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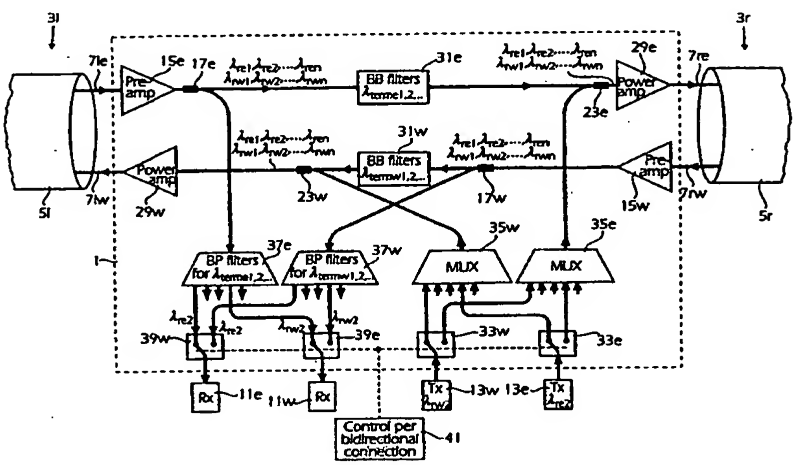

(57) Abstract

An optical fiber network of WDM type comprises two fibers (7e, 7w) which carry light signals propagating in opposite direction and which are arranged in a ring configuration, in which always one link (2) between two neighbouring nodes is inactive but provides a standby-link which is used for failure in another link, in the case of which the previously inactive link is made active. An add and drop (1) node used in the network has band blocking filters (31e, 31w) connected in a fiber (7e, 7w) between a drop coupler (17e, 17w) and an add coupler (23e, 23w), taking out a share of the light power in each direction to be received through bandpass filters (37e, 37w) in receivers (11e, 11w) and adding new wavelength channels produced in transmitters (13e, 13w) respectively. Switches (39e, 39w; 33e, 33w) are used for receiving and transmitting on the wavelength channels in correct directions. The positions of the switches can be changed when the inactive link (2) has to become one of the two links directly connected to the node. A very efficient use of the wavelength channels in the network can then be achieved for nodes having a minimun of in-line components and particularly a minimum of in-line filtering components.

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AN OPTICAL WDM NETWORK HAVING AN EFFICIENT USE OF WAVELENGTHS AND A NODE THEREFOR

TECHNICAL FIELD

The invention relates to an optical fiber network using wavelength division multiplexing (WDM) and an add and drop node for such a network.

BACKGROUND OF THE INVENTION

Optical multi-channel systems employing wavelength multiplexing are used both in new networks and in order to enhance the transmission capability of existing optical fiber networks. Thus, information channels which previously had to be transmitted on a plurality of separate fiber pairs are forwarded on a single fiber pair in WDM networks. Using optical wavelength division multiplexed channels means that a plurality of serial information signals, i.e. a plurality of serial binary signals, are transmitted on the same optical fiber by modulating such a serial signal on a light signal, also called carrier, having a definite wavelength and then combining the modulated light signals in an optical coupler or optical multiplexer to a composite light signal on the considered optical fiber. The signal primarily modulated on a monochromatic light signal or carrier together with the carrier can be called a channel or traffic channel.

Self-healing optical fiber networks having a ring configuration are disclosed in U.S. patent 5,442,623, but they are not particularly adapted to WDM-signalling. A similar network designed for WDM-traffic is disclosed in the International patent application PCT/SE98/00136. The networks described in these documents use an extra protecting fiber pair between each pair of nodes.

Optical wavelength multiplexing can generally be used in different optical fiber network configurations or architectures having e.g. only a single fiber pair between a pair of nodes. Such an architecture is the FlexBus^{TM} concept as described in B.S. Johansson et al., "Flexible bus: A self-restoring optical ADM ring architecture", Electronics Letters, 5th Dec. 1996, Vol. 32, No. 25, and U.S. patent application 08/421,734, this architecture comprising a ring configuration of optical links connecting a plurality of nodes. The FlexBus^{TM} concept has emanated from the need for protecting ring networks against fiber cuts and optical amplifier failures, and to solve the problem, often associated with ring network architectures, of circulating signals and noise. In the FlexBus^{TM} architecture one section of the fiber ring is always made passive or inactive by means of optical switches or amplifiers. This intentionally introduced break effectively eliminates all problems associated with circulating signals and hence allows that less circuit components can be used and circuit elements having lower performance can be used, while still retaining the shortest longest path possible. In the case of a real failure of a link, that link which previously has been intentionally made inactive is made active and the failed link now becomes the inactive link, what can be described by having the inactive link moved from its former position to the failed section. This procedure is called that "the bus flexes", and thereby the traffic is restored.

In the FlexBus^{TM} channel blocking or selection filters placed in the lines are not needed, which alleviates the problems associated with concatenated filtering. The signal from one transmitter can be sent in both directions simultaneously without causing interference, and the same wavelength can be used in both directions, thus allowing the same number of bi-directional connections to be set up as the number of wavelengths that are used in the network.

With the maturing of filtering and switching technology it would, however, be beneficial to be able to reuse wavelengths more than once in order to be able to set up more connections and thus increase network capacity for the limited number of wavelengths that are feasible in a network with regard to available optical amplifier gain-bandwidth, realistic filter bandwidths and frequency stability of filters and light sources. Thus another implementation of a node architecture, based on the FlexBus^{TM} but including a plurality of blocking filters and switches connected in-line, i.e. in the direct path of a fiber of the network or bus through the node, was invented and is disclosed in the published International patent application WO 96/31025 and is called the "Rearrangeable FlexBus^{TM}". That implementation is capable of a very efficient use of the wavelengths. In the published International patent application WO 96/24998 an algorithm scheme for wavelength allocation in Rearrangeable FlexBus^{TM} networks is disclosed. An add/drop node for a WDM network is disclosed in the published International patent application WO 98/49794 which can allow some reuse of wavelengths.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an add and drop node for a network of the kind Rearrangeable FlexBus^{TM} as described above having a minimum of in-line components and enhancing the reliability of the network but still having the good properties of the FlexBus^{TM} and the efficient use of wavelengths as defined in the concept of the Rearrangeable FlexBus^{TM}.

The problem to be solved by the invention is how to achieve a node construction for a network of the kind Rearrangeable FlexBus^{TM} operating substantially as the nodes of that bus allowing an efficient wavelength allocation in the network and allowing the network and the nodes to operate in a reliable way. In particular, in the network, the nodes should not transmit information over links where it is not needed or where it will not be received by any down-stream node.

Thus generally, an add/drop node is provided which is arranged to be connected in an optical fiber WDM network. The network has a ring configuration including two fibers carrying light signals in opposite directions. Thus, the network has links connecting neighbouring nodes. For protection, the network always has one inactive link carrying no light signals and the network is constructed so that the inactive link can be made active and another link can be made inactive. Since the network is WDM-type, information is carried in the network in a plurality of separate wavelength bands for the light signals. The add/drop node comprises in the conventional way drop couplers and add couplers for each direction for

taking out a share of signals at the add/drop node and for adding signals in the add/drop node respectively. The node further comprises as conventional receivers and transmitters for receiving light signals in wavelength bands in the add/drop node and transmitters for transmitting light signals in wavelength bands from the add/drop node into the network. The add/drop node further comprises a band blocking filter arranged between a drop coupler and an add coupler for blocking in one direction all wavelengths which are received and/or terminated in the node from that direction. Preferably, the band blocking filter is arranged for blocking all wavelengths which are received in the node from either direction and are reused in the node.

In the node at least one switch is provided, which advantageously is connected according to one of the following cases:

- to a receiver and the drop couplers for allowing the receiver to receive from either one of the two opposite directions, or
- to a transmitter and the add couplers for allowing the transmitter to transmit in either one of the two opposite directions.

Preferably, two separate switches are provided, one connected according to the first of said cases and one connected according to the second of said cases.

Further switching means can be provided for letting, in a first position of the switching means, the light signals of a wavelength pass through the node in a substantially unaffected way and in a first direction. The same wavelength is then received from a second direction opposite to the first one. In a second different position of the switching means they block the wavelength as received from the second direction. The switching means for receiving in a wavelength band and at each instant only in one direction can comprise a 2:3 switch having its inputs connected to bandpass filters for the wavelength band. Each bandpass filter is then connected to a drop coupler, so that the switch receives light from opposite directions. The 2:3 switch preferably has one of its outputs connected to a receiver for the wavelength band and another output connected to an add coupler for light signals in a second direction opposite to the first one.

The optical fiber WDM network built from such add/drop nodes and possibly other nodes having the same or corresponding switching facilities allows an efficient use of wavelengths. Thus, the nodes can be arranged to use at least one wavelength band in such a way that the wavelength band is used by at least two separate first nodes for transmitting to second nodes, which are different from each other, in a first direction and is used by only one third node to transmit to a fourth node in a second direction opposite to the first direction.

In the network a transmission span can be defined to be the piece of the network between a node transmitting information in a wavelength band and another node receiving the information on the same wavelength band. Then advantageously, the transmission spans of the at least two separate first nodes for the wavelength band in the first direction are arranged

not to overlap each other. The transmission span of the third node for the wavelength in the second direction preferably extends over the spans of the at least two separate first nodes for the wavelength in the first direction.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described by way of non-limiting embodiments with reference to the accompanying drawings, in which

Fig. 1 is a general schematic view of a prior art optical fiber network of WDM type using the flexible bus architecture,

Fig. 2 is a block diagram of a prior art add and drop node of a simple configuration intended to be used in the network of Fig. 1,

Fig. 3 is a block diagram of an add and drop node similar to that of Fig. 2 allowing a limited reuse of wavelengths in the network of Fig. 1,

Fig. 4 is a block diagram of an add and drop node allowing an efficient reuse of wavelengths and intended to be used in the network of Fig. 1,

Fig. 5 is a block diagram of an add and drop node similar to that of Fig. 4 but having slightly improved transmission performance, and

Fig. 6 is a graph illustrating the assignment of wavelengths in a network of the kind illustrated in Fig. 1 having nodes according to Figs. 3, 4 or 5.

DESCRIPTION OF PREFERRED EMBODIMENTS

A network using the basic flexible bus structure for WDM communication on optical fibers is illustrated in Fig. 1. A plurality of optical, add and drop nodes 1 are connected to each other by links 3 to form a network or bus comprising a physical ring structure having as basic elements a pair of optical fibers 7e, 7w connected to form two parallel fiber rings. Each fiber ring carries light propagating in a definite direction, the propagation directions of the two rings being opposite to each other. Thus, in one of the fiber rings light always propagates in the counter-clockwise direction, in the embodiment of Fig. 1 the inner ring 7e, this direction being called the east direction hereinafter. In the other one 7w of the rings of the pair of fiber rings light always propagates in the opposite direction, i.e. in the clockwise direction, as seen in Fig. 1, this direction being called the west direction. A node 1 in the bus structure is thus physically connected only to two neighbouring nodes, a left node and a right node. The connections of a considered node 1 thus include a left physical link 3l comprising a west line cable 5l and a right physical link 3r comprising an east line cable 5r, the other end of each link 3l, 3r being connected to the neighbouring left and right node respectively. Each piece 5l, 5r of line cables comprises a pair of optical fibers 7lw, 7lw and 7re, 7re respectively, where in one 7le, 7re of the fibers of a fiber pair in a link 3l, 3r light always propagates in one direction, as in the east direction as seen in Fig. 1, and in the other one 7lw, 7rw of the fibers of the fiber pair in a link light always propagates in the opposite direction, in the clockwise or west direction, as seen in Fig. 1. Furthermore, a node 1 is connected to or contains receivers 11 and transmitters 13 for converting optical signals to

electrical signals and vice versa, the electrical signals being transferred or received respectively from other devices, links or networks, not shown.

One of the links 3 of the ring structure is always deactivated, see the link 2 in Fig. 1, so that at least no light carrying the useful information to be transferred in the network can pass therethrough, in neither direction. This prevents that such light signals and ASE noise can circulate along the ring structure in several turns, ASE noise being amplified spontaneous emission produced in in-line optical amplifiers which are usually included in the nodes 1. When there is a failure in a link between neighbouring nodes, the network can be reconfigured so that this link will then be the deactivated one whereas the previously deactivated link (2) is now activated and operates like the other active links (3) in the ring structure passing signals in the two opposite directions.

A basic structure of a node 1 in the basic flexible bus structure of Fig. 1 is shown in the block diagram of Fig. 2. The optical WDM traffic comprising a plurality of WDM channels having definite, separate wavelengths, each channel occupying a wavelength band around the wavelength of the channel, enters the node from the left or in the east direction and from the right or in the west direction on the fibers 7le and 7rw respectively. The incoming signals can be amplified in optional optical preamplifiers 15e, 15w respectively in which the light signals are amplified. The incoming light is then split in drop couplers 17e, 17w. These couplers are optical power splitters that feed a portion of the total power of the light propagating in one direction in the bus, through an optical combining coupler 19, adding the deflected power portions from each direction to each other, to a bank 21 of filters, which can also be called an optical demultiplexer, having one or more bandpass filters for wavelengths used in the transmission in the network. Thus the filter bank 21 filters out channels, each channel carrying information in a definite wavelength band. The filtered-out light signals are then forwarded to opto-electrical receivers 11, one optical receiver being arranged for each received channel.

The remaining part of the light power split in the drop couplers 17e, 17w is forwarded through the node 1 and is in add couplers 23e, 23w mixed with new traffic to be added in the node. This new traffic is obtained from electro-optical transmitters 13, which each one transmits optical signals of a wavelength band or of a channel different from that of the other transmitters. The output signals of the transmitters 13 are added to each other in an optical combining coupler or optical multiplexer 25, the resulting combined signal then being split in a splitting coupler 27 in two portions having equal power, one of the two portions being transmitted to one of the add couplers 23e, 23w and the other portion being transmitted the other one of the add couplers. The light signals obtained from the add couplers 23e, 23w for each direction are fed to the fibers 7re, 7lw, which are contained in the links 3r, 3l connected to the node and carrying light going out from the node, through optional optical power amplifiers 29e, 29w.

In the node design as illustrated in Fig. 2 the lack of in-line blocking filters and in-line

switches should be observed and in particular that light propagates through or passes the node in a substantially unaffected or uninterrupted way. Furthermore, the transmitters 13 are sending in and the receivers 11 are listening to both traffic directions simultaneously. The left side or the right side amplifiers 15e, 29w or 15w, 29e respectively can be used to deactivate the respective links or segments 3l, 3r connecting the node to the two neighbouring nodes. This is made in the case where this link is to be the deactivated one, such as in the case of a failure of this link. Such a failure can be caused e.g. by one of the fibers of the pair of the link being broken or by one of the optical amplifiers connected to this link being defective.

The bus structure and node design according to Figs. 1 and 2 are described in the above cited article by B.S. Johansson et al. and in the cited U.S. patent application 08/421,734. However, this structure only allows that a considered wavelength or channel is used once in the network in each direction, such as for communicating between two nodes. A node architecture allowing a reuse of wavelengths, i.e that a channel or wavelength is used more than once for transferring information in one direction, is disclosed in the cited International patent application WO 96/31025 resulting in a more efficient use of available wavelengths. However, this prior node design has a multitude of demultiplexers and switches connected in-line, i.e. in the direct path of a fiber of the network or bus through the node. Still, this prior node allows a very efficient use of the wavelength range or equivalently a very efficient use of available channels.

A design of an add and drop node based on the design according to Fig. 2 that can allow some reuse of wavelengths is illustrated in Fig. 3. There, the node structure differs from that of Fig. 2 only in that for each propagation direction in the bus a wavelength blocking or band blocking filter 31e, 31w is connected between the drop coupler 17e, 17w and the add coupler 23e, 23w connected to the fiber for the respective direction. The band blocking filters 31e, 31w block that or those wavelength bands which are terminated in the node for the traffic direction of the fiber, in which the respective blocking filter is connected. The node according to Fig. 3 has only band blocking filters connected in-line and no switches, what makes the node more reliable than the above-mentioned prior node allowing a reuse of wavelengths. In this node, like the node of Fig. 2, the same information signals are simultaneously transmitted in the opposite directions, on both links connected to the node, what limits the possible reuse of wavelengths and does not allow moving the inactive segment needed for the flexbus network according to Fig. 1. Thus, some switching of channel directions must be provided if a node of the kind illustrated in Fig. 3 is to be used in such a network.

Hence, in Fig. 4 a block diagram of the general architecture of a node for a network of the kind illustrated in Fig. 1 is shown, this node being obtained from the node of Fig. 3 by adding switches and by providing filter blocks and multiplexers for each direction. It can be observed that the switches are not connected in-line. The only attenuating in-line elements are the blocking filters 31e, 31w in addition to the always necessary couplers. The node

architecture of Fig. 4 allows a reuse of wavelengths for networks of the flexbus type as illustrated in Fig. 1 resulting in an enhanced capability of the network system, i.e. that more nodes can be used in a network for the same number of multiplexed wavelengths. The reuse of wavelengths in the node is as efficient as in the prior art node according to the cited International patent application WO 96/31025. However, the node as depicted in Fig. 4 has no in-line switches and a minimum of in-line blocking filters causing a minimum of concatenated filtering effects what totally makes it more efficient than the prior art node.

For the node illustrated in Fig. 4 the light signals propagating in the east direction and incoming to a considered node include at least all the wavelengths λ_{re1}, λ_{re2}, ..., λ_{ren}, which correspond to all those channels, which arrive in this direction and are both terminated and reused in a node in this direction. In the corresponding way the light signals propagating in the west direction and incoming to the considered node include at least all the wavelengths λ_{rw1}, λ_{rw2}, ..., λ_{rwn}, which correspond to all those channels for west travelling signals, which are both terminated in a node and reused in a node in the west direction. The two sets $[\lambda_{re1}, \lambda_{re2}, \ldots, \lambda_{ren}]$ and $[\lambda_{rw1}, \lambda_{rw2}, \ldots, \lambda_{rwn}]$ of wavelengths terminated and reused in any node of the network can for example contain different wavelengths. Other wavelength channels not included in these sets may also exist, which can e.g. be used for carrying information bidirectionally between two nodes. In the normal case, as appears from Figs. 6a and 6b, the light signals incoming to an inner node in one direction will at least include the union of the wavelength sets mentioned, i.e. all the wavelengths $[\lambda_{re1}, \lambda_{re2}, \ldots, \lambda_{ren}, \lambda_{rw1}, \lambda_{rw2}, \ldots, \lambda_{rwn}]$.

Each of the blocking filters 31e, 31w in a node according to Fig. 4 blocks only the wavelengths λ_{terme1}, λ_{terme2}, ... and λ_{termw1}, λ_{termw2}, ... respectively of those channels which are terminated in the node for the respective direction, the blocked wavelengths being determined by assuming that the node is connected as an inner node at a standard position in the network. An end node is herein defined to be a node connected directly to the inactive link of the bus network and an inner node is defined as a node which is not an end node. When the inactive link 2 is relocated, i.e. when "the bus flexes", a former end node can become an inner node and vice versa, but of course the same wavelengths are blocked in the node. All wavelengths which are not included in the set of wavelengths $[\lambda_{terme1}, \lambda_{terme2}, \ldots]$ of channels terminated in the east direction, are just passed through the node in the east going direction in a basically unaffected way. In the same way all wavelengths which are not included in the set of wavelengths $[\lambda_{termw1}, \lambda_{termw2}, \ldots]$ of channels not terminated in the node in the west direction, are just passed through the node in the west going direction in a basically uninterrupted way.

The principle of allocating and reusing a wavelength in a self-healing annular network of the flexbus type as shown in Fig. 1 is illustrated by the diagram of Fig. 6 showing a flexible bus having eight nodes 1 joined in a line configuration by a bus consisting of links 3 between neighbouring nodes and each comprising two optical fibers, the outermost nodes

being joined by an inactive link 2 also comprising two optical fibers. Above the line of nodes communication in the east direction is shown wherein a wavelength λ_{re2} is reused and a different wavelength λ_{rw2} is not reused but used for transmitting information between the two end nodes and beneath the line of nodes is shown a symmetric use of the same wavelengths where for all communication in the west direction the wavelength λ_{rw2} is reused and the wavelength λ_{re2} is used for transmitting information between the two end nodes.

In Fig. 6 it is seen, that a wavelength may only be reused in one of the directions on the bus, but can be reused in any convenient connection in that direction, as long as none of the connections, for which the wavelength is used, overlap each other. In the reverse direction, i.e. on the other fiber of network fiber bus, the same wavelength is only allowed to be used once, and has to have a span that at least overlaps all of the spans for which the wavelength is used in the first direction. This implies that if a wavelength is reused in any one of the directions, the receiver-transmitter pair on that connection have to use different wavelengths. A wavelength that is terminated in a node does not have to be reused in that node, but can be used for transmission in the same direction by a node located in the same direction from the considered node. The use of a wavelength for a bi-directional connection is only allowed if that wavelength is not used for any other connection in the network, this case not being illustrated in the figure.

In Fig. 4 the same reference numerals as in Figs. 2 and 3 are used for identical or corresponding elements. In both directions in the middle of the node, thus the blocking filters 31e, 31w are connected between that output of the drop coupler 17e, 17w which carries the signal to be forwarded through the node and an input of the respective add coupler 23e, 23w. The light signal incoming in each direction includes at least all the wavelengths, which for signals propagating in a considered direction correspond to all those channels, which are both terminated in a node and reused in a node of the system in this direction, these nodes being the same one or different nodes. A wavelength channel is said to be terminated in a node if it is received in the node, i.e. if there is a receiver 11e or 11w for this channel in the node, and it is said to be reused in a considered node if two conditions are fulfilled, namely if it is used for transmission from the node, i.e. if there is a transmitter 13w, 13e for this channel in the considered node, and at the same time the same channel is used for transmitting information in the same direction by another node.

In the diagram of a node according to Fig. 4, which can e.g. be the node X in Fig. 6, those components are illustrated which are required for receiving from a node on the left or west side on only one wavelength λ_{re2}. This wavelength signal is thus included in the total light signal travelling in the eastern direction and this wavelength is reused in the east going direction from the node in order to carry information from the node in this direction. The directions are indicated for the case that the node depicted in Fig. 4 is connected as an inner node like the node X in Fig. 6. In the similar way those components are shown in Fig. 4, which are required for receiving information on a single wavelength λ_{rw2} in the reverse

direction, the western direction. The channel of this wavelength is thus terminated in the node and the wavelength is reused in the western direction for carrying information from the node. In this case we can then see, that the same wavelength is used for receiving signals from another node at one side of the considered node and for transmitting signals to another node at the opposite side of the considered node. Only the channels reused in a node have to be blocked by the in-line band blocking filters 31e, 31w in the node, but it may be advantageous to block also all wavelengths, which are terminated in the node but not reused in the node, if such wavelengths exist, see the discussion of the dynamical range of the light signal in conjunction with Fig. 5.

In order to allow an efficient use of wavelengths and thus of the dynamical range a signal must only be transmitted from the considered node in that direction in which it can reach the node to which it is to be communicated, considering the position of the inactive link 2. The standard connection of a node is when it is connected as an inner node and not as an end node, the term end node here being taken to mean a node connected directly to the inactive link, as indicated above. For the standard connection the transmitters of a node are in a natural way divided in transmitters 13e for sending in the east going direction and transmitters 13w for sending in the west going direction. Each transmitter 13e, 13w has its output terminal connected to a simple 1:2 switch 33e, 33w. The outputs of these transmitter switches 33e, 33w are connected to two multiplexer blocks 35e, 35w corresponding to the multiplexer 35 of Figs. 2 and 3, one multiplexer block 35e for traffic in the east direction and one multiplexer block 35w for traffic in the west direction. The output of the multiplexer 35w for the west direction is connected to an input of the add coupler 23w for the fiber carrying traffic in the west direction and the output of the multiplexer 35e for the east direction is connected to an input of the add coupler 23e for the east going direction.

Like the embodiments according to Figs. 2 and 3, the optional preamplifiers 15e, 15w are each followed by a drop coupler 17e, 17w. The drop couplers couple a suitable share of the power of the received light to separate blocks or banks 37e, 37w of bandpass filters, one block 37e containing bandpass filters for each of the wavelengths λ_{terme1}, λ_{terme2}, ..., which correspond to channels in the east going direction which are terminated in the node, and another block 37w containing bandpass filters for each of the wavelengths λ_{termw1}, λ_{termw2}, ..., which correspond to channels carrying traffic in the west going direction and terminated in the node. The output of each of the filters in such a filter block 37e, 37w, which thus carries a light signal of a specific wavelength or of a specific narrow wavelength interval, is connected to a 2:1 switch 39e, 39w, one such switch 39e, 39w thus being arranged per wavelength or channel terminated in the node. By means of each such switch 39e, 39w the direction is chosen, from which the respective wavelength is to be received, i.e. whether it is to be received from the east side or from the west side in relation to the considered node. The output terminals of the two bandpass filters which filter out the same wavelength and are included in the two filter banks 37e, 37w are thus connected to the same 2:1 switch 39e,

39w. The receiver 11e, 11w for a specific wavelength λ_{re2} or λ_{rw2} is connected to the output terminal of such a 2:1 switch 39e, 39w, the switch being set in the appropriate position depending on the location of the source of information, i.e. to the east or to the west of the considered node, and generally also depending on the location of the deactivated link segment 2. All the switches 33e, 33w, 39e, 39w can be controlled by a control unit 41, programmed to set the switches in correct positions depending on the network status, i.e. the location of the node in relation to the presently inactive link 2.

The filters in the filter blocks 37e, 37w could also be arranged directly in or at the respective receiver 11e, 11w, the filter blocks then being replaced with power splitters, not shown, splitting the light power in equal parts, one part for each receiver 11e, 11w in the considered direction.

If in the node of Fig. 3 a certain wavelength λ_{termek} or λ_{termwk} is to be received from one direction and reused in the same direction, then the same wavelength must be able to propagate through the node on the other fiber in the opposite direction, if a maximum reuse of the available wavelengths is to be achieved, see Fig. 6 and the International patent application WO 96/24998 cited above describing efficient wavelength allocation. In Fig. 4 the positions of the switches 33e, 33w and 39e, 39w are illustrated for a node not being an end node, i.e. in the case in which it is not connected at one of its sides to the inactive link 2. If the "bus has to flex", i.e. if the inactive link has to become active and another link has to become inactive, owing to some failure in this another link and the considered node then becomes connected directly to the inactive link, one of the receiver switches 39e, 39w then has to change its position and that one of the switches 33e, 33w connected to a transmitter 13e, 13w which sends to the same node also has to change its position. The receiver and transmitter switches 39e, 39w and 33e, 33w for changing the paths for a correct connection with another node, i.e. for receiving from and transmitting correctly to the other node, can thus be linked to the same triggering point, simplifying the procedure which must be executed by the control unit 41. It can be observed that the wavelengths blocked by the blocking filters 31e, 31w in each direction do not have to be changed for a flexing situation owing to the specific allocation of wavelengths.

Some channels may not be reused in any of the directions, such node-to-node-connections using two own wavelengths, which can suitably be the same wavelength. For these channels it is not necessary to have duplicated demultiplexing bandpass filters included in the filter blocks 37e, 37w and hence the corresponding 2:1 switches 39e, 39w are not needed for these wavelengths. The 1:2 switches 33e, 33w for the transmitters 13e, 13w are not needed either for these wavelengths. This reduction in components may improve reliability and cost.

The node design according to Fig. 4 makes it possible to achieve a maximum reuse of wavelengths and thus a maximum wavelength efficiency, while using a minimum amount of in-line filtering and no in-line switches. A certain wavelength is, however, not blocked in the

reverse direction in the receiving node. This implies that that wavelength channel will continue to propagate all the way to the end node and will consequently unnecessarily take up part of the available dynamic range on that part of the bus, which implies a potential degradation of the transmission potential on that part. The alternative node architecture illustrated by the block diagram of Fig. 5 can be used in order to mitigate this problem. The same reference numerals as in Fig. 4 are used in Fig. 5 for identical or corresponding elements. In this node design the blocking filters 31e, 31w for the east going and west going traffic respectively are connected like the blocking filters 31e, 31w of Fig. 3 and are each arranged to block all channels that are terminated in the node, both in the east and west going directions, so that the set [λ_{terme1}, λ_{terme2}, ...] of wavelengths blocked by the bandblocking filters 31e in the node in the east going direction contains the same wavelengths as the set [λ_{termw1}, λ_{termw2}, ...] of wavelengths blocked in the node by the bandblocking filters 31w in the west going direction.

In Fig. 5 the node is illustrated to only receive information on a wavelength λ_{re2} which for the case that the node is connected in the standard way as an inner node is included in the light travelling in the eastern going direction and to reuse this wavelength. The transmitter 13e and the receiver 11w are adapted to transmit and receive on this wavelength. Since a wavelength which is received from and is reused in one direction has to be capable of passing through the node on the other fiber in the reverse direction, it is necessary to bypass the blocking filter 31e in the node for this direction. This is allowed by the introduction of 2:3 switch 43e instead of the simpler 2:1 receiver switch 39e according to Fig. 4, this 2:3 switch 43e being arranged to connect the pass-through channel to the multiplexer 35w. The two inputs of the 2:3 switch 43e are connected to bandpass filters for this wavelength λ_{re2} included in each of the filter blocks 37e, 37w. The middle output terminal of the 2:3 switch 43e is connected to the receiver 11e and one of the two outer output terminals of the switch is connected to an input of that one 35w of the multiplexers 35e, 35w which has its output terminal coupled to the add coupler 23w for traffic in the opposite direction compared to that of the reused wavelength. The other outer output terminal of the 2:3 switch 43e can be connected to a monitoring device 45. In the case, where the considered node receives information on the wavelength λ_{re2} in light propagating in the east direction, as is the standard case for the considered node, the switch 43e is set to connect the output signal of the filter for λ_{re2} in the block 37e of filters for east going traffic to the receiver 11e and to connect the output signal of the filter for λ_{re2} in the block 37w of filters for west going traffic to the input of the multiplexer 35w for west going traffic. In the case where the inactive link 2 has to be changed so that the same wavelength λ_{re2} has to instead be received from the opposite direction, i.e. is contained in the west going traffic, the switch 43e has to change its position. Then the output signal of the filter for λ_{re2} in the block 37w of filters for west going traffic is connected to the receiver 11e, whereas the output signal of the filter for λ_{re2} in the block 37e of filters for east going traffic is connected to the monitoring device 45.

The transmitter 13e is connected through a 1:2 switch 33e to either one of the multiplexers 35e, 35w as in Fig. 4, the switch being in its standard state, where it receives information on the wavelength band around λ_{re2} in the east-going traffic, connected to the multiplexer 35e for the traffic going in the same, eastern direction. The switches 33e, 43e are controlled by a common control unit 41.

For each wavelength received and reused in the node there will be arranged components corresponding to those illustrated in the lower portion of Fig. 5. In a node being in its standard state, for traffic normally going in the west direction some of the components will have a mirrored construction and mirrored connection compared to what is shown and the switches will be set in opposite positions compared to those illustrated in Fig. 5.

The efficient allocation of wavelengths for a self-healing network has been discussed above in conjunction with Fig. 6. Generally, for a certain traffic demand, a number of different solutions to the allocation of wavelengths requiring a minimum total number of wavelengths may often be found. In searching for a good solution it may often be helpful to utilize the basic symmetry of the two directions resulting from the bi-directionality of the connections.

Achievable network capacities and wavelength efficiency are as follows. Consider a situation when there are N nodes and the available number of wavelengths in the network are N_λ. For the flexible ring structure having simple nodes as illustrated in Fig. 2, the maximum number of connections are then equal to N_λ, independently of the type of traffic, that is whether it is a hubbed, meshed or adjacent traffic demand. The required number of wavelengths allowing communication between all N nodes (the "full mesh" traffic situation) is given by N(N - 1)/2.

For nodes having the complex architecture as indicated in Figs. 4 or 5, the possible number of connections, N_c will depend on the traffic demands as follows:

$N_c = N_\lambda$ for hubbed traffic (where e.g. one node is the "hub")

$N_c \approx 2 N_\lambda$ for fully meshed traffic (traffic between all nodes)

$N_c = N \cdot N_\lambda/2$ for purely adjacent traffic demands (traffic only between neighbouring nodes)

The necessary number of wavelengths for a full mesh of N nodes is given by:

$N_\lambda = N^2/4$ for N even

$N_\lambda = (N^2 - 1)/4$ for N odd

An add/drop node has thus been described, which when used in a self-healing annular network allows an efficient wavelength allocation and an efficient use of the dynamic range. It has a minimum of in-line components which otherwise could degrade signals passing through the node in an uninterrupted way.

CLAIMS

1. An add/drop node arranged to be connected in an optical fiber WDM network, the network having a ring configuration of two fibers carrying light signals in opposite directions, the network comprising links connecting neighbouring nodes, the network always having one inactive link carrying no light signals and being arranged to allow that the inactive link is made active and another link is made inactive, the network carrying light signals in a plurality of separate wavelength bands, the add/drop node comprising drop couplers and add couplers for each direction for taking out a share of the signals at the add/drop node and for adding signals in the add/drop node respectively and further comprising receivers for receiving light signals in wavelength bands in the add/drop node and transmitters for transmitting light signals in wavelength bands from the add/drop node into the network, the add/drop node further comprising a band blocking filter arranged between a drop coupler and an add coupler for blocking in one direction all wavelengths which are received and/or terminated in the node from that direction, **characterized by** at least one switch, the least one switch being connected according to one of the following cases:

- to a receiver and the drop couplers for allowing the receiver to receive from either one of the two opposite directions, or
- to a transmitter and the add couplers for allowing the transmitter to transmit in either one of the two opposite directions.

2. An add/drop node according to claim 1, **characterized in** that the band blocking filter is arranged to block all wavelengths which are received in the node from either direction and are reused in the node.

3. An add/drop node according to claim 2, **characterized by** switching means for letting in one position of the switching means a wavelength pass through the node, substantially unaffected, in a first direction, the same wavelength being received from a second direction opposite to the first one, the switching means in another position blocking the wavelength as received from the second direction.

4. An add/drop node according to claim 3, **characterized in** that the switching means for receiving on a wavelength band in a direction comprises a 2:3 switch having its inputs connected to bandpass filters for the wavelength band, each bandpass filter being connected to a drop coupler, so that they receive light from opposite directions.

5. An add/drop node according to any of claims 3 - 4, **characterized in** that the switching means for receiving on a wavelength band in a first direction comprises a 2:3 switch having one of its outputs connected to a receiver for the wavelength band and another output connected to an add coupler for light signals in a second direction opposite to the first one.

6. An optical fiber WDM network having a ring configuration of two fibers carrying light signals in opposite directions, the network including a plurality of nodes and links connecting neighbouring nodes, the network always having one inactive link carrying no light

signals and being arranged to allow that the inactive link is made active and another link is made inactive, the network carrying information in a plurality of separate wavelength bands, the nodes comprising drop couplers and add couplers for each direction for taking out a share of signals at the nodes and adding signals in the nodes respectively and receivers for receiving light signals in wavelength bands in the node and transmitters for transmitting light signals in wavelength bands from the nodes into the network, **characterized in** that the nodes are arranged to use at least one wavelength band in such a way that the wavelength band is used by at least two separate first nodes for transmitting to second nodes, which are different from each other, in a first direction and is used by only one third node to transmit to a fourth node in a second direction opposite to the first direction.

7. An optical fiber WDM network according to claim 6, in which a transmission span is the piece of the network between a node transmitting information in a wavelength band and another node receiving the information on the same wavelength band, **characterized in** that the transmission spans of the at least two separate first nodes for the wavelength band in the first direction do not overlap each other.

8. An optical fiber WDM network according to any of claims 6 - 7, in which a transmission span is the piece of the network between a node transmitting information in a wavelength band and another node receiving the information on the same wavelength band, **characterized in** that the transmission span of the third node for the wavelength band in the second direction extends over the spans of the at least two separate first nodes for the wavelength band in the first direction.

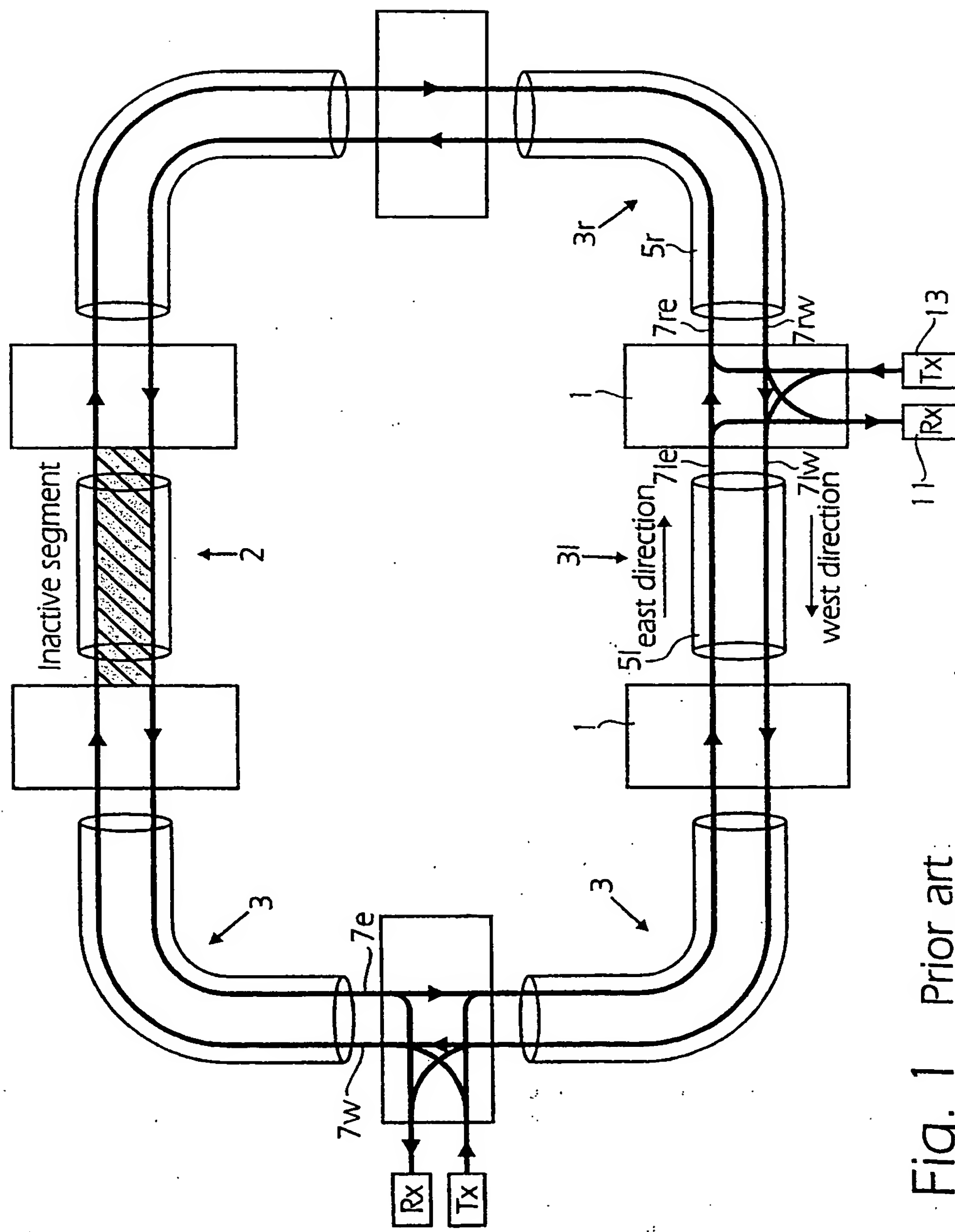
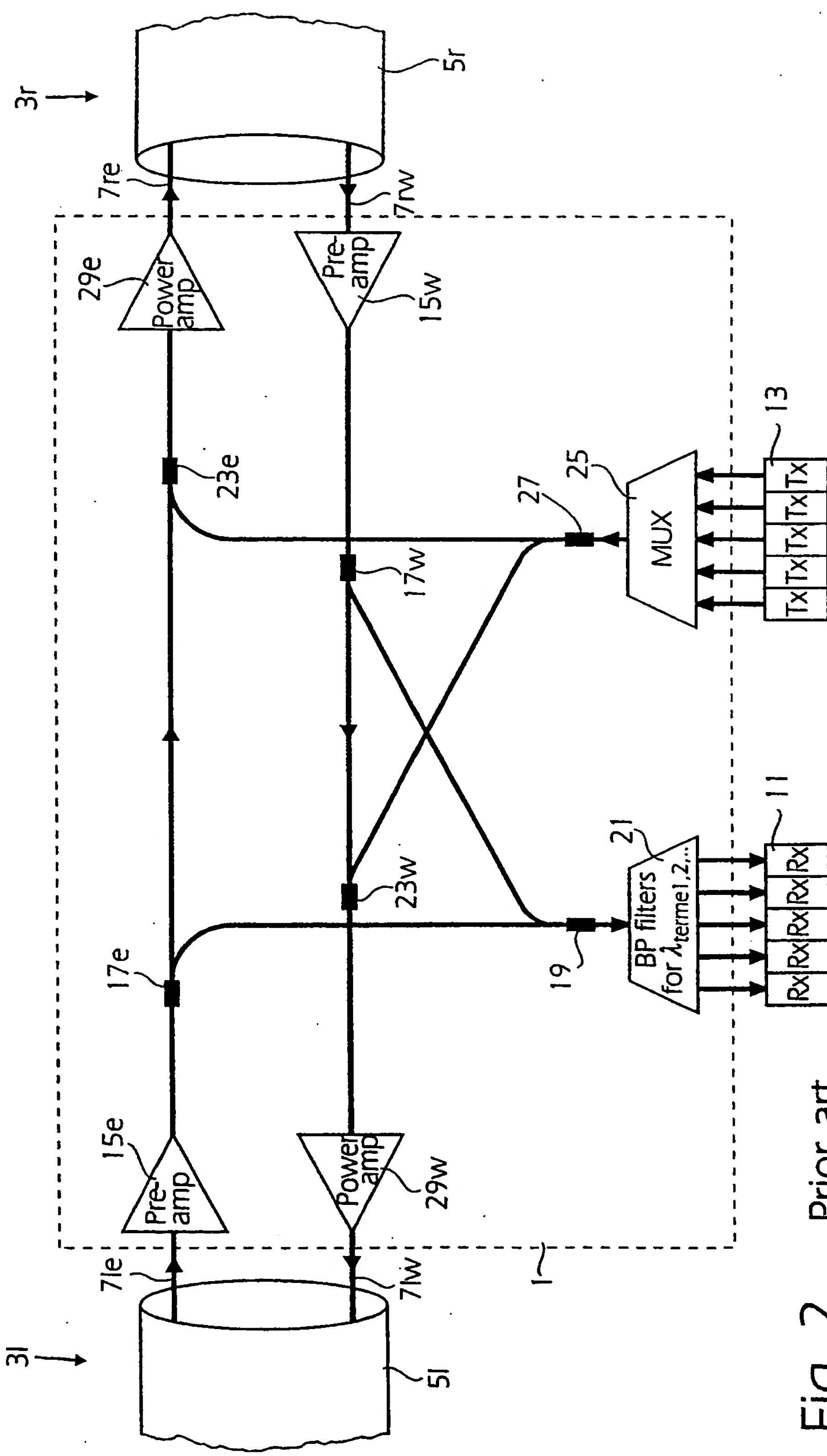


Fig. 1 Prior art



Prior art

Fig. 2

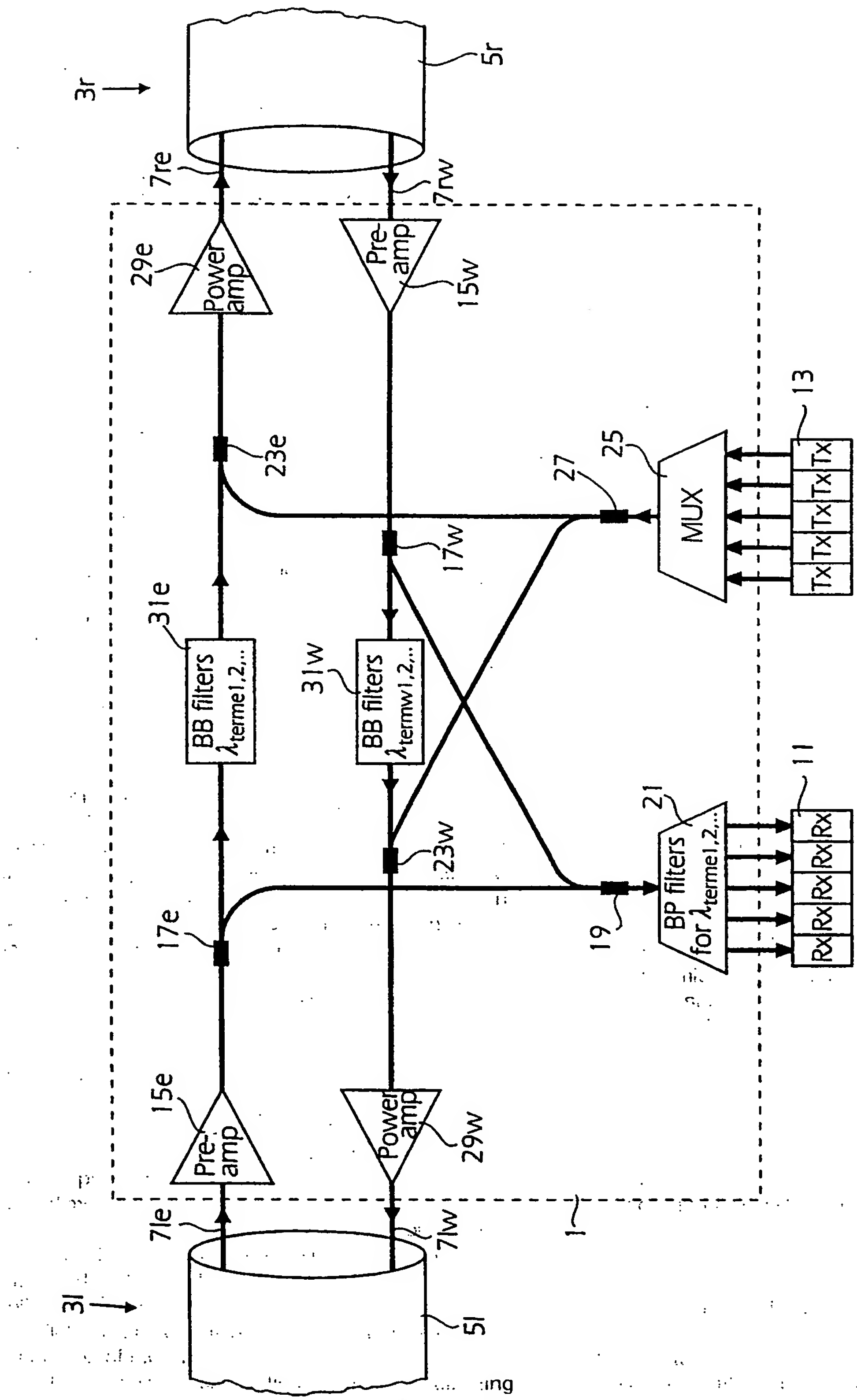

3r
5r
7re
7rw
29e
Power amp
Pre-amp
15w
13
23e
27
25
MUX
Tx Tx Tx Tx Tx Tx
17w
31e
BB filters $\lambda_{terme1,2,...}$
31w
BB filters $\lambda_{termw1,2,...}$
11
21
23w
BP filters for $\lambda_{terme1,2,...}$
Rx Rx Rx Rx Rx
17e
19
15e
Pre-amp
Power amp
29w
7le
7lw
1
3l
5l

Fig. 3

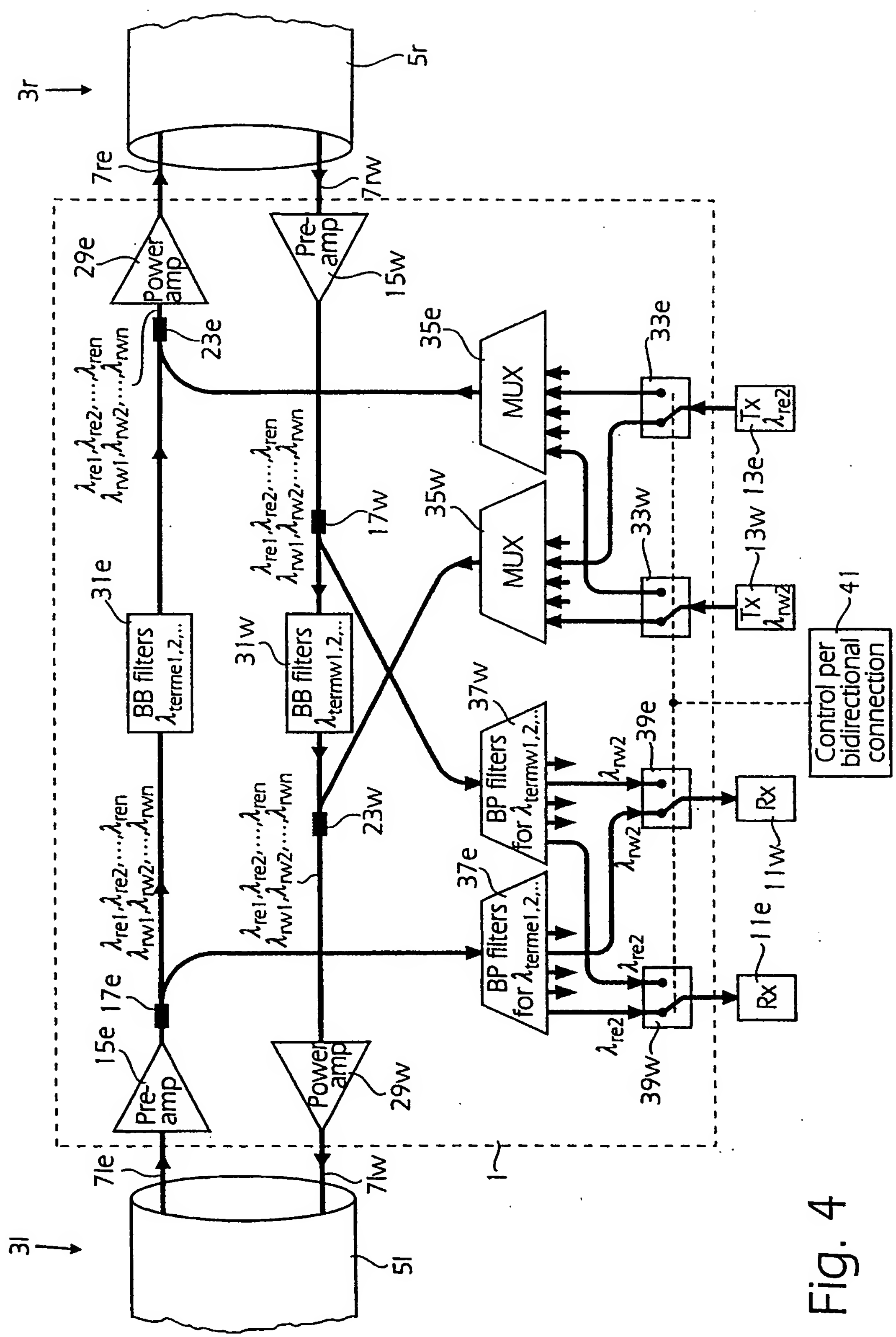

3r
5r
7re
7rw
Power amp
29e
Pre-amp
15w
23e
35e
MUX
33e
Tx
13e
35w
MUX
33w
13w
Tx
17w
31e
BB filters
31w
BB filters
37w
BP filters
39e
Rx
11w
Control per bidirectional connection
41
23w
37e
BP filters
Rx
11e
39w
17e
15e
Pre-amp
Power amp
29w
7le
7lw
1
3l
5l

Fig. 4

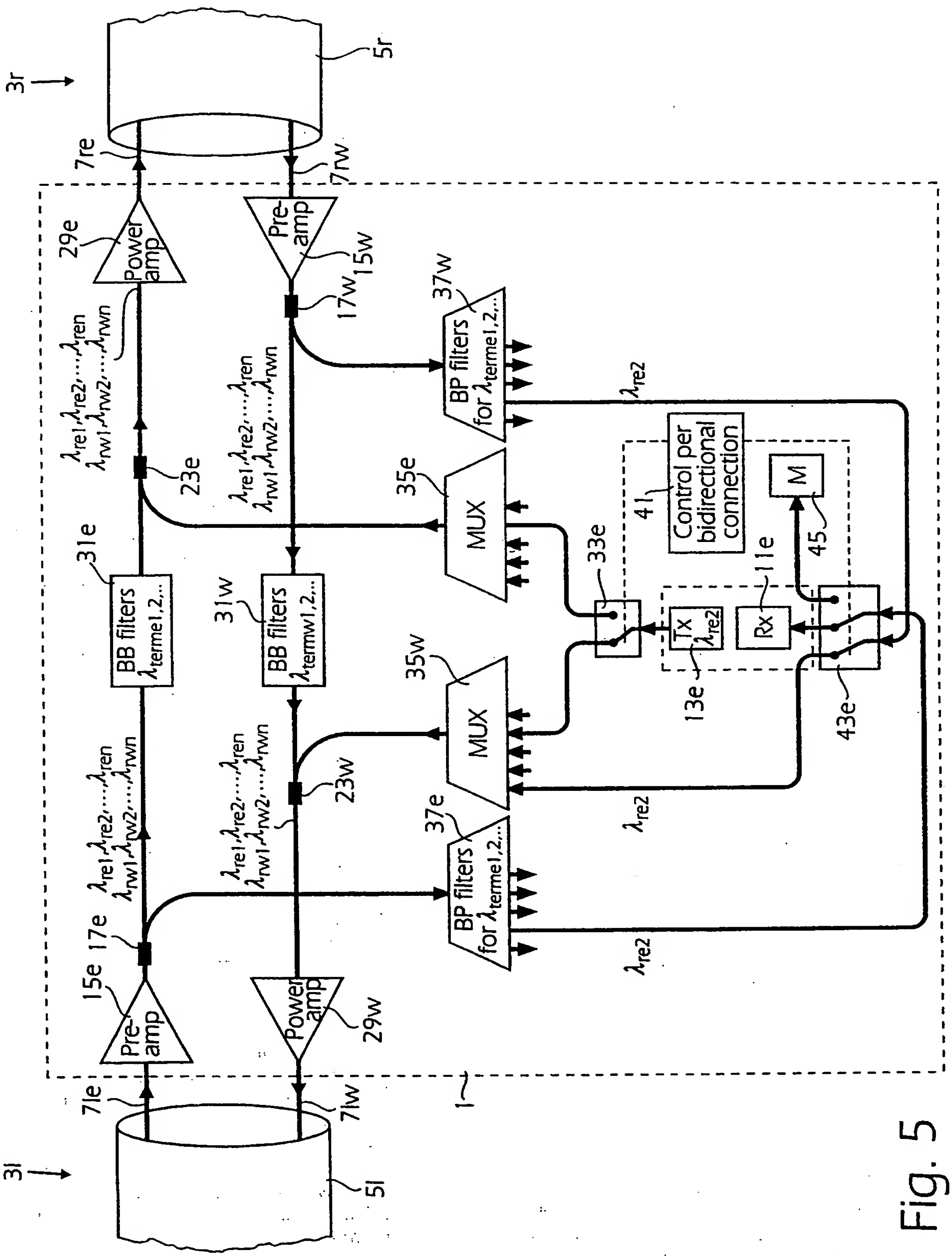

3r
5r
7re
7rw
29e
Power amp
Pre-amp
15w
17w
37w
BP filters for $\lambda_{terme1,2...}$
$\lambda_{re1}, \lambda_{re2}, ..., \lambda_{ren}$
$\lambda_{rw1}, \lambda_{rw2}, ..., \lambda_{rwn}$
23e
35e
MUX
31e
BB filters $\lambda_{terme1,2...}$
31w
BB filters $\lambda_{termw1,2...}$
35w
MUX
33e
41
Control per bidirectional connection
M
45
11e
Tx λ_{re2}
Rx
13e
43e
λ_{re2}
23w
37e
BP filters for $\lambda_{terme1,2...}$
17e
15e
Pre-amp
Power amp
29w
7le
7lw
3l
5l
1

Fig. 5

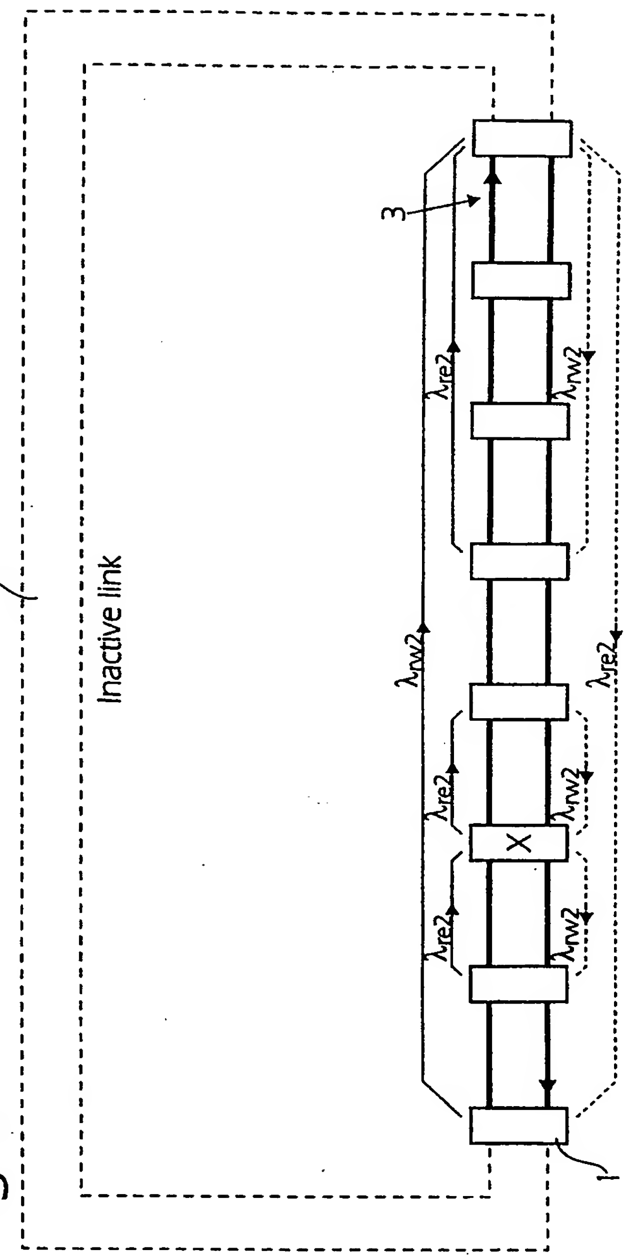


Fig. 6

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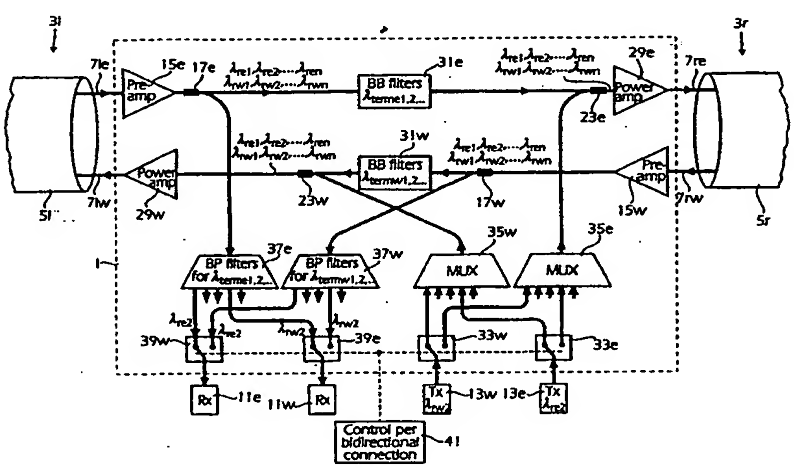
(54) Title: AN OPTICAL WDM NETWORK HAVING AN EFFICIENT USE OF WAVELENGTHS AND A NODE THEREFOR



(57) Abstract

An optical fiber network of WDM type comprises two fibers (7e, 7w) which carry light signals propagating in opposite direction and which are arranged in a ring configuration, in which always one link (2) between two neighbouring nodes is inactive but provides a standby–link which is used for failure in another link, in the case of which the previously inactive link is made active. An add and drop (1) node used in the network has band blocking filters (31e, 31w) connected in a fiber (7e, 7w) between a drop coupler (17e, 17w) and an add coupler (23e, 23w), taking out a share of the light power in each direction to be received through bandpass filters (37e, 37w) in receivers (11e, 11w) and adding new wavelength channels produced in transmitters (13e, 13w) respectively. Switches (39e, 39w; 33e, 33w) are used for receiving and transmitting on the wavelength channels in correct directions. The positions of the switches can be changed when the inactive link (2) has to become one of the two links directly connected to the node. A very efficient use of the wavelength channels in the network can then be achieved for nodes having a minimun of in–line components and particularly a minimum of in–line filtering components.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 99/00993

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H04B 10/213, H04J 14/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H04B, H04J, H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0769859 A1 (PIRELLI CAVI S.P.A.), 23 April 1997 (23.04.97), see the whole document --	1-5
P,A	WO 9849794 A2 (TELEFONAKTIEBOLAGET LM ERICSSON), 5 November 1998 (05.11.98), cited in the application (whole document) --	1-5
A	WO 9624998 A1 (TELEFONAKTIEBOLAGET LM ERICSSON), 15 August 1996 (15.08.96), page 1, line 6 - page 3, line 6, claims 1-5, cited in the application --	1-5

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 99/00993

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9808322 A1 (ALCATEL ALSTHOM COMPAGNIE GENERALE D'ELECTRICITE), 26 February 1998 (26.02.98), see the whole document --	1-5
Y	EP 0769859 A1 (PIRELLI CAVI S.P.A.), 23 April 1997 (23.04.97), column 5, line 4 - line 39, claims 1-6, abstract --	6-8
Y	EP 0716521 A2 (CSELT CENTRO STUDI E LABORATORI TELECOMUNICAZIONI S.P.A.), 12 June 1996 (12.06.96), column 4, line 22 - line 48; column 7, line 5 - line 17, claims 1-10, abstract --	6-8
A	US 5546403 A (CHIYOKO YAMAMOTO ET AL), 13 August 1996 (13.08.96), column 1, line 27 - line 62, abstract --	6-8
A	EP 0788249 A1 (PIRELLI CAVI S.P.A.), 6 August 1997 (06.08.97), column 3, line 7 - column 4, line 40, claims 1-6, abstract -- --------	6-8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE99/00993

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

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because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
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Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See next page.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

1st invention: claims 1-5.
2nd invention: claims 6-8.

The special technical feature of the invention according to independent claim 1 is an add/drop node in an optical fiber WDM network, the network having a ring configuration and a band blocking filter arranged between a drop and add coupler, The invention is characterized by the switch connections to the receiver or to the transmitter, for allowing the receiver to receive, and the transmitter to transmit from respectively in either one of two opposite directions.

The special technical feature of the invention according to claim 6 is an optical WDM network having a ring configuration with add/drop nodes characterized by that the nodes are arranged to use at least one wavelength band in such a way that the wavelength band is used by at least two separate first nodes for transmitting to second nodes, which are different form each other, in a first direction and is used by only one third node to transmit to a forth node in a second direction opposite to the first direction.

It is not mentioned in the independent claim 6 something about the filter and the switch connections, which are the special technical feature of claim 1. Thus, the two inventions are not considered to have the same or corresponding special technical feature. Therefore, the application contains two independent inventions and lacks in unity.

INTERNATIONAL SEARCH REPORT
Information on patent family members

02/12/99

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PCT/SE 99/00993

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(54) Optical transmission system and optical branching apparatus

(57) In the optical transmission system of wavelength-division multiplexing, a plurality of wavelengths to be wavelength-division multiplexed are divided into a plurality of wavebands (for example, wavebands L, M and H, and the waveband EX for communication between trunk stations), each waveband consisting of one or more wavelengths. Each of branch stations 16-1 ~ 16-4 is connected with a trunk cable 14 through each of optical branching apparatuses 18-1 ~ 18-6 which is provided with one or more add/dropping elements to effect add/drop of the waveband(s) allotted to the associated one of the branch stations to be connected therewith. Optical branching apparatus for general purpose comprises an optical transmission path having add/dropping element for each of wavebands L, H and M, in addition to a through optical transmission path. A burden of having a great number of optical branching apparatuses in stock is reduced, since the optical paths to effect add/drop of wavebands allotted to branch stations 16-1~16-4 to be connected can be used selectively or in combination thereof.

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to an optical transmission system and an optical branching apparatus, and more specifically to an optical transmission system and an optical branching apparatus for which a technology of optical wavelength-division multiplex is applied.

Related Art

The technology of optical wavelength-division multiplex is effective as means for increasing a transmission capacity. The number of logical transmission channels is increased corresponding to the number of multiplexed wavelengths. For example, a system for allotting a particular wavelength to each branch station is now being considered.

FIG. 15 is a schematic structural block diagram of a conventional system wherein an optical wavelength allotted to each branch station is subjected to add/drop on a trunk line. Generally in optical fiber transmission, two optical fiber lines for up and down are used, and, accordingly, a pair of optical fiber lines makes a unit. A trunk cable 114 consisting of an optical fiber line 114U for up link and an optical fiber line 114D for down link is laid between a trunk station 110 and a trunk station 112. The trunk cable 114 is capable of transmission of a wavelength-division multiplexed optical signal comprising at least four optical wavelengths λ1, λ2, λ3 and λ4. Then the optical wavelengths λ1, λ2 and λ3 are allotted to branch stations 116-1, 116-2 and 116-3, respectively, and transmission of signals between each branch station 116-1, 116-2, 116-3 and the trunk station 110 or 112 is made with a particular optical wavelength allotted to each branch station. The wavelength λ4 is used for data transmission between the trunk stations 110 and 112.

Optical branching apparatuses 118-1, 118-2 and 118-3, each comprising an add/dropping element for effecting add/drop of wavelengths λ1, λ2 and λ3 respectively corresponding to each branch station 116-1, 116-2 and 116-3, are connected to the trunk cable 114 (specifically to a down optical fiber line 114D in FIG. 15). The optical branching apparatus 118-1 drops the wavelength λ1 out of the wavelength-multiplexed optical signal comprising the wavelengths λ1 ~ λ4 which has been input from the upstream of the down optical fiber line 114D, and supplies the dropped wavelength λ1 to the branch station 116-1. And the apparatus 118-1 wavelength-multiplexed the optical signal of the wavelength λ1 from the branch station 116-1 with the wavelength-multiplexed optical signal comprising the wavelengths λ2 and λ4 which remains after dropping of the wavelength λ1, and supplies the resulted wavelength-multiplexed optical signal to the next optical branching device 118-2. The subsequent optical branching apparatus 118-2 and 118-3 perform the same function as the optical branching apparatus 118-1, except their respectively allotted wavelengths. Namely, the optical branching apparatus 118-2 and 118-3 supply the dropped wavelengths λ2 and λ3 to the branch stations 116-2 and 116-3 respectively, and wavelength-multiplexed the optical signals of the wavelengths λ2 and λ3 from the branch stations 116-2 and 116-3 with the wavelengths remained in the optical signals after dropping the wavelengths of λ2 and λ3, respectively.

The trunk station 112 receives the wavelength-multiplexed optical signal comprising the wavelengths λ1 ~ λ4 supplied from the optical branching apparatus 118-3 through the down optical fiber line 114D and processes each wavelength as required and/or transmits the signal to the trunk station 110 via an up optical fiber line 114U.

As such, each branch station 116-1, 116-2, and 116-3 can transmit data bi-directionally with the trunk station 110 and/or 112 with the respectively allotted wavelengths of λ1, λ2 and λ3. The trunk stations 110 and 112 can transmit data with each other, using the wavelength λ4.

One or more optical branch stations 118-1 ~ 118-3 may be connected to the up optical fiber line 114U. The branch station may also be connected to both the optical branching device connected to the up optical fiber line 114U and the optical branching device connected to the down optical fiber line 114D.

FIG. 16 is a schematic structural block diagram of a conventional system wherein the branch stations are chain connected between two trunk stations. Numerals 120 and 122 designate the trunk stations, numerals 124-1 ~ 124-3 designate the branch stations. The trunk station 120 is connected to the branch station 124-1 by means of an optical cable 126-1, the branch station 124-1 and the branch station 124-2 are connected to each other by an optical cable 126-2, the branch station 124-2 and the branch station 124-3 are connected to each other by an optical cable 126-3, and the branch station 124-3 is connected to the trunk station 122 by an optical cable 126-4. Each of the optical cables 126-1 ~ 126-4 contains therein a pair of optical fiber lines.

For example, as in the system of FIG. 15, at least four optical wavelengths λ1, λ2, λ3 and λ4 are used, of which the wavelengths λ1, λ2, and λ3 are respectively allotted to the branch stations 124-1, 124-2 and 124-3, thereby the signals are transmitted between the trunk station 120 or 122 and each branch station with the allotted optical wavelengths, while the wavelength λ4 is used for data transmission between the trunk stations 120 and 122.

The trunk station 120 outputs the wavelength-multiplexed optical signal of the wavelengths λ1, λ2 and λ3 directed to the branch stations 124-1, 124-2 and 124-3 and the wavelength λ4 directed to the trunk station 122 to the down optical fiber line of the optical cable 126-1.

The wavelength-multiplexed optical signal comprising of the wavelengths λ1 ~ λ4 and transmitted through the down optical fiber line of the optical cable 126-1 is input into the branch station 124-1 wherein the wavelength λ1 is dropped and subjected to signal receiving and processing. The remaining wavelengths λ2 ~ λ4 are multiplexed with the wavelength λ1 directed to the trunk station 120 or 122, and thus multiplexed wavelengths are output to the down optical fiber line of the optical cable 126-2. Similarly, in each of the branch stations 124-2 and 124-3, the wavelength λ2 or λ3 is dropped respectively out of the optical signals from the branch stations 124-1 or and 124-2 and subjected to signal receiving and processing, and the remaining of the input optical signal from which the wavelength λ2 or λ3 has been excluded is multiplexed with the wavelength λ2 or λ3 directed to the trunk station 120 or 122, and the thus wavelength-multiplexed optical signal is output to the down optical fiber line of the optical cable 126-2.

The trunk station 122 receives the optical signal comprising the wavelengths λ1 ~ λ4 from the branch station 124-3 and subjects them to the signal receiving and processing as required, and/or transmits the signal to the up optical fiber line of the optical cable 126-4.

The optical signal transmitted through the up optical fiber line of each of the optical cable 126-1 ~ 126-4 is processed exactly in the same manner.

As described above, the optical signal comprising the wavelengths respectively allotted to the branch stations 124-1 ~ 124-3 is subjected to add/drop in each of branch stations 124-1 ~ 124-3.

With the conventional system of FIG. 16, which is, for example, a submarine cable system, portions of the optical cables 126-1 ~ 126-4 adjacent to each of branch stations 124-1 ~124-3 are located at shallow positions near the land, and a possibility for the optical cables to be cut by fishing boats becomes high. With the conventional system of FIG. 16, if any of the optical cables 126-1 ~ 126-4 is cut at any portion, communication between the ends at the cut portion is no longer possible. To avoid such trouble, generally a bypass path (shown by a broken line) is provided to bypass each of branch stations 124-1 ~ 124-3, and the bypass path can be switched over by a remote control.

With the conventional system of FIG. 15, the wavelengths of add/dropping elements incorporated in the optical branching apparatuses 118-1 ~ 118-3 are fixed. Therefore, for the purpose of maintenance, it is necessary to have spares for all of the optical branching devices 118-1 ~ 118-3 in stock. However, a spare of the optical branching device 118-1 cannot be used as the optical branching device 118-2. This causes an increase of the cost. Another disadvantage of this conventional system is that it cannot flexibly deal with traffic fluctuation in each of the branch stations 124-1 ~ 124-3.

On the other hand, with the conventional system of FIG. 16, many stations are chain connected, and, therefore, the system is basically vulnerable to troubles. Even if the system was so structured to have a bypass path to bypass the troubled portion, a response to switch-over to the bypass path was slow in this conventional system, and, consequently, temporary disconnection of communication could not be avoided. Further, providing the bypass path creates a security problem. Another disadvantage of the conventional system of FIG. 16 is that the quality of signal is liable to be deteriorated, because the optical signal is transmitted through each station.

Either of the above-described conventional system has the disadvantage of not being able to flexibly deal with traffic fluctuation in each of the branch stations 118-1 ~ 118-3; and 124-1 ~ 124-3.

OBJECT AND SUMMARY OF THE INVENTION

An object of the present invention is to solve these problems and to provide an optical transmission system which can flexibly deal with traffic fluctuation with easy maintenance.

Another object of the present invention is to provide an optical transmission system which is capable of allotting a plurality of wavelengths to each branch station.

A further object of the present invention is to provide an optical transmission system which can avoid giving any substantial affect of a trouble occurred in a branching passage to other portion.

A still further object of the present invention is to provide an optical branching apparatus which is capable of freely selecting wavelengths to be subjected to add/drop process.

According to the present invention, a plurality of wavelengths of wavelength-division multiplexing transmission system are divided into a plurality of wavebands, each waveband comprising one or more wavelengths, and one or more optical branching apparatus connected to each branch station are provided with add/dropping means for effecting add/drop of one or more desired wavebands. With this arrangement, each branching apparatus can access to the trunk cable with a waveband as a unit, and the wavelengths available for use can be changed or added afterwards, thereby to flexibly deal with fluctuation of traffic. Further, it is not necessary to provide an optical branching apparatus for add/dropping each wavelength, and the burden of having the optical branching apparatuses in stock is reduced, and maintenance is made easier.

Provision of one or more wavelengths which cannot be subjected to add/drop by each optical branching apparatus allows, for example, assuring of a direct communication network between trunk stations. Thereby, communication paths between trunk stations are ensured even when a trouble is occurred in a branch cable, and, thus, a system which is strong enough to withstand such troubles can be provided.

In the case where the trunk cable has a plurality of pairs of optical fiber lines, different wavebands may be

subjected to add/drop on each pair of optical fiber lines, respectively, thereby, general purpose optical branching apparatuses can be utilized fully without wasting any of them.

The optical branching apparatus according to this invention comprises a plurality of add/drop optical transmission means having add/dropping means for effecting add/drop of each waveband to be subjected to add/drop respectively, when wavelengths to be wavelength-division multiplexed are divided into a plurality of wavebands; and through optical transmission means. A combination or selection of these optical transmission means allows to add/drop one or more desired wavebands, and, therefore, an optical branching apparatus for general use can be provided. Consequently, a stock of branching apparatuses ready for use when trouble occurs can be reduced, which, in turn, greatly reduces the cost required for maintenance.

For the plurality of add/drop optical transmission means, it is preferable to provide optical amplifier means for each add/drop optical transmission means, except at least one add/drop optical transmission means. Provision of the add/drop optical transmission means without having the optical amplifier means can prevent the system from having a plurality of optical amplifier in case of add/dropping a plurality of wavebands. Further, bypass means for selectively bypassing add/dropping means is provided to at least one add/drop optical transmission means having optical amplifier means, so that optical transmission means having only optical amplifier means can be formed, which is possible to be used in combination with add/drop optical transmission means having no optical amplifier means.

Add/drop optical transmission means and through optical transmission means may be provided for each unit comprising a pair of optical fiber lines consisting of up and down optical fiber lines, so that this arrangement can be easily applied for an optical transmission system having a pair of optical fiber lines as a unit.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an example of division of wavebands of an embodiment of this invention.

FIG. 2 is a schematic structural block diagram of the optical transmission system of this embodiment.

FIG. 3 is a schematic structural block diagram of a general purpose optical branching apparatus of this embodiment.

FIG. 4 shows a connecting example for effecting add/drop of the waveband H on a pair #1 of optical fiber lines; and add/drop of the waveband M on a pair #2 of optical fiber lines.

FIG. 5 is an equivalent circuitry arrangement of the connection of FIG. 4.

FIG. 6 shows a connecting example for effecting add/drop of the wavebands M, H on the pair #1 of optical fiber lines, and add/drop of the waveband L on the pair #2 of optical fiber lines.

FIG. 7 is an equivalent circuitry arrangement of the connection of FIG. 6.

FIG. 8 is another example of division of wavebands.

FIG. 9 is a further example of division of wavebands.

FIG. 10 is a still further example of division of wavebands.

FIG. 11 is an example of division of wavebands for an increased capacity of communication between the trunk stations.

FIG. 12 is an example of division of wavebands for allotting three adjacent wavelengths to the same pair #1 or #2 of optical fiber lines.

FIG. 13 is an example of division of wavebands comprising the waveband L consisting of three wavelengths, and the waveband H consisting of two wavelengths.

FIG. 14 is an example of division of wavebands for using the wavelength $\lambda 4$ for communications between the trunk stations commonly on the pairs #1 and #2 of optical fiber lines.

FIG. 15 is a schematic structural block diagram of a conventional system.

FIG. 16 is a schematic structural block diagram of another conventional system.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

An embodiment of the invention is described below in detail with reference to the accompanying drawings.

With this embodiment, a plurality of wavelengths of a wavelength-division multiplexing transmission system are divided into a plurality of groups, namely, a plurality of wavebands, each waveband consisting of one or more adjacent wavelengths, and wavelength characteristics for each add/dropping device are set based on such waveband as a unit. The description will be made for a transmission system of eight wavelengths $\lambda 1 \sim \lambda 8$.

FIG. 1 shows an example of division of wavebands. In this example of division of FIG. 1, the wavelengths of $\lambda 1$ and $\lambda 8$ at both ends are allotted for direct communication between trunk stations, and wavebands L, M and H, each consisting of two adjacent wavelengths, are formed. In other words, the waveband L consists of $\lambda 2$ and $\lambda 3$, the waveband M consists of $\lambda 4$ and $\lambda 5$, and the waveband H consists of $\lambda 6$ and $\lambda 7$. The wavebands for direct communication between trunk stations are designated as EX.

Further in FIG. 1, each wavelength is alternately and exclusively allotted to a pair #1 of optical fiber lines or a pair #2 of optical fiber lines. By so doing, separation of wavelengths in a receiving station (particularly in a branch station) becomes easy, so that wavelengths can be more closely multiplexed on optical fiber lines. Further, a confusion caused by using same wavelength on

different pairs of optical fiber lines can be avoided. Namely, with this embodiment, wavelengths λ1, λ3, λ5 and λ7 are allotted to the pair #1 of optical fiber lines, and wavelengths λ2, λ4, λ6 and λ8 are allotted to the pair #2 of optical fiber lines. In other words, wavelength-division multiplexed optical signal consisting of λ1, λ3, λ5 and λ7 transmits on the pair #1 of optical fiber lines, and wavelength-division multiplexed optical signal consisting of λ2, λ4, λ6 and λ8 transmits on the pair #2 of optical fiber lines,

Needless to say, even when the same wavelength is allotted to the pairs #1 and #2 of optical fiber lines, the optical signals of the same wavelength do not interfere with each other, because the pairs #1 and #2 of optical fiber lines are physically, namely, spatially, separated from each other, so that there will be no trouble in data communication or transmission.

FIG. 2 is a schematic structural block diagram of an embodiment of this invention. Numeral 10 designates a trunk station A and numeral 12 designates a trunk station B, and a trunk cable 14 containing therein the pair #1 of optical fiber lines and the pair #2 of optical fiber lines is laid between the trunk stations 10 and 12. Branch stations 16-1 ~ 16-4,... are connected to one or both of the pairs #1 and #2 of optical fiber lines by way of optical branching devices 18-1 ~ 18-6,....

Optical branching apparatus 18-1 comprises an optical element for add/dropping of the waveband L to the pair #2 of optical fiber lines of the trunk cable 14 and is connected to the branch station 16-1 through a branch cable 20-1. The branch cable 20-1 consists of a total of four optical fiber lines, namely, two optical fiber lines for effecting add/drop on the up optical fiber line of the pair #2 of optical fiber lines of the trunk cable 14, and two optical fiber lines for effecting add/drop on the down optical fiber line of the pair #2 of optical fiber lines of the trunk cable 14. The waveband L is subjected to add/drop on the pair #2 of optical fiber lines, and, therefore, it is understood from the TABLE of FIG. 1 that the branch station 16-1 makes access to the pair #2 of optical fiber lines with the wavelength λ2.

Optical branching apparatus 18-2 comprises an optical element for effecting add/drop of the waveband M on the pair #1 of optical fiber lines of the trunk cable 14 and is connected to the branch station 16-2 through a branch cable 20-2. Optical branching apparatus 18-3 comprises an optical element for effecting add/drop of the waveband H on the pair #2 of optical fiber lines of the trunk cable 14 and is connected to the branch station 16-2 through a branch cable 20-3. Each of branch cables 20-2 and 20-3 is, similar to the branch cable 20-1, consisting of the total of four optical fiber lines. Branch cables 20-2 and 20-3 may be made in an integrally formed single cable. The waveband M is subjected to add/drop on the pair #1 of optical fiber lines, and the waveband H is subjected to add/drop on the pair #2 of optical fiber lines, and, therefore, the branch station 16-2 makes access to the pair #1 of optical fiber lines with the wavelength λ5, and access to the pair #2 of optical fiber lines with the wavelength λ6, as can be understood from the TABLE of FIG. 1.

Optical branching apparatus 18-4 comprises an optical element for effecting add/drop of the waveband H on the pair #2 of optical fiber lines of the trunk cable 14 and is connected to the branch station 16-3 through a branch cable 20-4. The branch cable 20-4 is consisting of four optical fiber lines, similarly to the branch cables 20-1 ~ 20-3. The waveband H is subjected to add/drop on the pair #2 of optical fiber lines, and, therefore, the branch station 16-3 makes access to the pair #2 of optical fiber lines with the wavelength λ6, as can be understood from the TABLE of FIG. 1.

Optical branching apparatus 18-5 comprises an optical element for effecting add/drop of the waveband H on the pair #1 of optical fiber lines of the trunk cable 14 and is connected to the branch station 16-4 through a branch cable 20-5. Optical branching apparatus 18-6 comprises an optical element for effecting add/drop of the waveband L on the pair #2 of optical fiber lines of the trunk cable 14 and is connected to the branch station 16-4 through a branch cable 20-6. Each of branch cables 20-5 and 20-6 is consisting of the total of four optical fiber lines, similarly to the branch cables 20-1 ~ 20-4. The branch cables 20-5 and 20-6 may be made in an integrally formed single cable. The waveband H is subjected to add/drop on the pair #1 of optical fiber lines, and the waveband L is subjected to add/drop on the pair #2 of optical fiber lines, and, therefore, the branch station 16-4 makes access to the pair #1 of optical fiber lines with the wavelength λ7, and access to the pair #2 of optical fiber lines with the wavelength λ2, as can be understood from the TABLE of FIG. 1.

With the above-described arrangement, the branch station 16-1, for example, can access to the pair #2 of optical fiber lines of the trunk cable 14 with the wavelength λ2, and can intercommunicate with the branch station 16-4 connected to the optical branching apparatus 18-6 which effects add/drop of the waveband L on the same pair #2 of optical fiber lines of the trunk cable 14. Between the trunk station 10 and the optical branching apparatus 18-1 on the pair #2 of optical fiber lines of the trunk cable 14, there is no optical branching apparatus for effecting add/drop of the waveband L, and, therefore, the trunk station 10 and the branch station 16-1 can communicate with each other with the wavelength λ2. Similarly, so long as no optical branching apparatus for effecting add/drop of the waveband L exists between the trunk station 12 and the optical branching apparatus 18-6 on the pair #2 of optical fiber lines of the trunk cable 14, the branch station 16-4 and the trunk station 12 can communicate with each other with the wavelength λ2.

When the communication from the branch station 16-4 to the trunk station 10 is desired, the optical signal of wavelength λ2 is transmitted to the branch station 16-1 by the optical branching apparatus 18-1. In this case,

however, if the optical signal has its destination address of, for example, trunk station 10, the branch station 16-1 can recognize that the received signal is not addressed thereto, and the branch station 16-1 will re-transmit the as-received optical signal to the pair #2 of optical fiber lines of the trunk cable 14. Thus, intercommunication between the trunk station 10 and the branch station 16-4 is made possible.

The branch station 16-2 is connected to both pairs #1 and #2 of optical fiber lines of the trunk cable 14, thereby it can communicate with the trunk station 10 or 12 with the wavelength λ5 through the branch cable 20-2, the optical branching apparatus 18-2 and the pair #1 of optical fiber lines of the trunk cable 14. Further, the branch station 16-2 can also communicate with the branch station 16-3 with the wavelength λ6 through the branch cable 20-3, the optical branching apparatus 18-3, the pair #2 of optical fiber lines of the trunk cable 14, the optical branching apparatus 18-4 and the branch cable 20-4. By re-transmission of the wavelength λ6 as is from the branch station 16-2 and the trunk station 12 by the branch station 16-3, the branch station 16-2 can communicate with the trunk station 12 also through the pair #2 of optical fiber lines of the trunk cable 14.

FIG. 3 is a schematic block diagram of a general purpose optical branching apparatus which can be utilized as optical branching apparatus 18-1 ~ 18-6, respectively, by internal connection thereof. In this embodiment, since all wavelengths available for use are, as shown in FIG. 1, divided into four wavebands L, M, H, and EX, pairs 30, 32, 34 and 36 of optical fiber lines are provided respectively for each waveband.

That is, the pair 30 of optical fiber lines is for the waveband EX and consisting of up and down through optical fiber lines 30U and 30D. The pair 32 of optical fiber lines is for the waveband H and consisting of up and down optical fiber lines 32U and 32D, each including an optical amplifier 32a and add/dropping element 32b for add/dropping the waveband H. The pair 34 of optical fiber lines is for the waveband L and consisting of up and down optical fiber lines 34U and 34D, each including an optical amplifier 34a and an add/dropping element 34b for add/dropping the waveband L. Although the reason will be described hereinafter, it should be noted that both up and down optical fiber lines 34U and 34D are respectively provided with a bypass optical fiber line 34e which is adapted to bypass the add/dropping element 34b by means of externally controlled optical switches 34c, 34d. The pair 36 of optical fiber lines is for the waveband M and consisting of up and down optical fiber lines 36U and 36D, each including an add/dropping element 36a for add/dropping the waveband M.

Because an optical amplifier is not provided in the pair 36 of optical fiber lines (optical fiber lines 36U and 36D), there will be only one optical amplifier present in the case where, for example, the pair 32 of optical fiber lines (optical fiber lines 32U and 32D) and the pair 36 of optical fiber lines (optical fiber lines 36U and 36D) are connected in series. In this case, both wavebands H and M can be subjected to add/drop. When add/drop of only the waveband M is desired, this can be achieved by connecting the pair 34 of optical fiber lines with the pair 36 of optical fiber lines in series, by bypassing the add/dropping element 34b by means of the bypass optical fiber lines 34e in the pair 34 of optical fiber lines. When such add/drop of a plurality of wavebands at the same time is not considered, each of the pairs 32, 34 and 36 of optical fiber lines can be constructed by comprising optical amplifiers and add/dropping elements for effecting add/drop of respectively designated wavebands.

Next, a connecting arrangement for add/dropping designated wavebands, as in the case of each of the optical branching devices 18-1 ~ 18-6 of FIG. 2, will be described. There are two possible connecting arrangements; one is to utilize remainder portions of optical fiber ends of the pairs 30 ~ 36 of optical fiber lines for interconnection between the pairs 30 ~ 36 of optical fiber lines by means of fusion or optical connectors, and the other is to connect the end of each of optical fiber lines with another optical fiber by means of fusion or optical connector. Here, in order that the relationship of connection between the pairs 30 ~ 36 of optical fiber lines can be readily understood, the description will be made by way of connecting the end of each optical fiber line with another optical fiber. For this purpose, a symbol x is added for an input end and a symbol y is added for an output end of each of the up and down optical fiber lines 30U and 30D; 32U and 32D; 34U and 34D; and 36U and 36D, to distinguish input ends from output ends of the pairs 30 ~ 36 of optical fiber lines.

Further, as shown in FIG. 3, in one of the trunk cables 14, the ends of up and down lines of pairs #1 and #2 of optical fiber lines are specified as 14a, 14b, 14c and 14d; and in other trunk cable 14, the ends of up and down lines of pairs #1 and #2 of optical fiber lines are specified as 14e, 14f, 14g and 14h. For connections between the trunk cable 14 and the pairs 30 ~ 36 of optical fiber lines will be described in the manner of connecting them by using another optical fibers. However, the connections can be achieved by using remainder of any of the optical fibers.

FIG. 4 illustrates a connecting arrangement for effecting add/drop of the waveband H on the pair #1 of optical fiber lines of the trunk cable 14, and effecting add/drop of the waveband M on the pair #2 of optical fiber lines of the trunk cable 14.

For add/drop of the waveband H, the necessary elements (the optical amplifier 32a and the add/dropping element 32b for add/dropping the waveband H) are provided on the pair 32 of optical fiber lines, and, therefore, add/drop of the waveband H can be achieved by connecting the pair 32 of optical fiber lines with the pair #1 of optical fiber lines. Specifically, the optical fiber end (output end) 14a of the pair #1 of optical fiber lines of the

trunk cable 14 is connected with the input end 32Ux of the up optical fiber line 32U of the pair 32 of optical fiber lines, and the output end 32Uy of the up optical fiber line 32U of the pair 32 of optical fiber lines is connected with the optical fiber end (input end) 14e of the pair #1 of optical fiber lines of the trunk cable 14. Then, the optical fiber end (output end) 14f of the pair #1 of optical fiber lines of the trunk cable 14 is connected with the input end 32Dx of the down optical fiber line 32D of the pair 32 of optical fiber lines, and the output end 32Dy of the down optical fiber line 32D of the pair 32 of optical fiber lines is connected with the optical fiber end (input end) 14b of the pair #1 of optical fiber lines of the trunk cable 14.

For the waveband M, its pair 36 of optical fiber lines is not provided with an optical amplifier, and, therefore, the optical amplifier 34a of the pair 34 of optical fiber lines of the waveband L is utilized. For this purpose, the optical switches 34c and 34d of the pair 34 of optical fiber lines are connected to the optical bypass fiber line 34e, thereby to disconnect the add/dropping element 34b of the waveband L. Then, the optical fiber end (output end) 14c of the pair #2 of optical fiber lines of the trunk cable 14 is connected with the input end 34Ux of the up optical fiber line 34U of the pair 34 of optical fiber lines, the output end 34Uy of the up optical fiber line 34U of the pair 34 of optical fiber lines is connected with the input end 30Dx of the down optical fiber line 30D of the pair 30 of optical fiber lines, the output end 30Dy of the down optical fiber line 30D of the pair 30 of optical fiber lines is connected with the input end 36Ux of the up optical fiber line 36U of the pair 36 of optical fiber lines, and the output end 36Uy of the up optical fiber line 36U of the pair 36 of optical fiber lines is connected with the optical fiber end (input end) 14g of the pair #2 of optical fiber lines of the trunk cable 14.

Then, the optical fiber end (output end) 14h of the pair #2 of optical fiber lines of the trunk cable 14 is connected to the input end 34Dx of the down optical fiber line 34D of the pair 34 of optical fiber lines, the output end 34Uy of the down optical fiber line 34D of the pair 34 of optical fiber lines is connected with the input end 30Ux of the up optical fiber line 30U of the pair 30 of optical fiber lines, the output end 30Uy of the up optical fiber line 30U of the pair 30 of optical fiber lines is connected with the input end 36Dx of the down optical fiber line 36D of the pair 36 of optical fiber lines, and the output end 36Dy of the down optical fiber line 36D of the pair 36 of optical fiber lines is connected with the optical fiber end (input end) 14d of the pair #2 of optical fiber lines of the trunk cable 14.

FIG. 5 illustrates an equivalent circuitry arrangement of the connection of FIG. 4. As it is understood from FIG. 5, this circuitry arrangement is adapted to effect add/drop of the waveband H on the up and down lines of the pair #1 of optical fiber lines of the trunk cable 14, and add/drop of the waveband M on the up and down lines of the pair #2 of optical fiber lines of the trunk cable 14. One optical amplifier is inserted in each of the up and down lines.

Next, an example of connection to effect add/drop of the wavebands M, H on the pair #1 of optical fiber lines, and add/drop of the waveband L on the pair #2 of optical fiber lines will be described. FIG. 6 illustrates this example of connection.

To effect add/drop of both the wavebands M and H on the pair #1 of optical fiber lines, the pairs 32 and 36 of optical fiber lines are connected in series. However, since it is necessary to arrange optical amplifiers in advance, the connections are made as follows. Namely, the optical fiber end (output end) 14a of the pair #1 of optical fiber lines of the trunk cable 14 is connected with the input end 32Ux of the up optical fiber line 32U of the pair 32 of optical fiber lines, the output end 32Uy of the up optical fiber line 32U of the pair 32 of optical fiber lines is connected with the input end 30Dx of the down optical fiber line 30D of the pair 30 of optical fiber lines, the output end 30Dy of the down optical fiber line 30D of the pair 30 of optical fiber lines is connected with the input end 36Ux of the up optical fiber line 36U of the pair 36 of optical fiber lines, and the output end 36Uy of the up optical fiber line 36U of the pair 36 of optical fiber lines is connected with the optical fiber end (input end) 14e of the pair #1 of optical fiber lines of the trunk cable 14.

The optical fiber end (output end) 14f of the pair #1 of optical fiber lines of the trunk cable 14 is connected with the input end 32Dx of the down optical fiber line 32D of the pair 32 of optical fiber lines; output end 32Dy of the down optical fiber line 32D of the pair 32 of optical fiber lines is connected with the input end 30Ux of the up optical fiber line 30U of the pair 30 of optical fiber lines; the output end 30Uy of the up optical fiber line 30U of the pair 30 of optical fiber lines is connected with the input end 36Dx of the down optical fiber line 36D of the pair 36 of optical fiber lines; and the output end 36Dy of the down optical fiber line 36D of the pair 36 of optical fiber lines is connected with the optical fiber end (input end) 14b of the pair #1 of optical fiber lines of the trunk cable 14.

About the add/drop of the waveband L on the pair #2 of optical fiber lines, the pair 34 of optical lines is connected with the pair #2 of optical fiber lines, since the pair 34 of optical fiber lines is provided with the necessary elements (optical amplifiers 34a and add/dropping elements 34b for add/dropping the waveband L). Of course, the optical switches 34c and 34d should be connected with the add/dropping elements 34b. Specifically, the optical fiber end (output end) 14c of the pair #2 of optical fiber lines of the trunk cable 14 is connected with the input end 34Ux of the up optical fiber line 34U of the pair 34 of optical fiber lines, and the output end 34Uy of the up optical fiber line 34U of the pair 34 of optical fiber lines is connected with the optical fiber end (input end) 14g of the pair #2 of optical fiber lines of the trunk cable 14. The optical fiber end (output end) 14h of

the pair #2 of optical fiber lines of the trunk cable 14 is connected with the input end 34Dx of the down optical fiber line 34D of the pair 34 of optical fiber lines, and the output end 34Dy of the down optical fiber line 34D of the pair 34 of optical fiber lines is connected to the optical fiber end (input end) 14d of the pair #2 of optical fiber lines of the trunk cable 14.

FIG. 7 illustrates an equivalent circuitry arrangement of the connection of FIG. 6. As it is understood from FIG. 7, this circuitry arrangement is adapted to effect add/drop of the waveband H and waveband M on the up and down lines of the pair #1 of optical fiber lines of the trunk cable 14, and to effect add/drop of the waveband L on the up and down lines of the pair #2 of optical fiber lines. One optical amplifier is inserted in both up and down lines of these pairs of optical fiber lines.

When one or more of the pairs 32~36 of optical fiber lines have remained, logically it is not necessary to make connections via the pair 30 of optical fiber lines. However, for laying these cables deep in the sea floor, each pair 30 ~ 36 of optical fiber lines is in a completely watertight structure. In this case, use of the through optical fiber lines is useful, and it makes it easy to deal with a case where any of the wavelengths are not subjected to add/drop on either pair #1 or #2 of optical fiber lines.

The optical branching apparatus illustrated in FIG. 3 can be utilized for general purpose, so long as it is not used to effect add/drop of the same waveband on both pairs #1 and #2 of optical fiber lines. Namely, it is sufficient to have the optical branching apparatus of FIG. 3 in stock, thereby the problem of the conventional art which requires to have many add/dropping elements for different wavelengths in stock is completely solved. Further, even after the cables have been laid, the wavelength allotted to branch stations may be changed within a range of wavebands that can be subjected to add/drop by any of the optical branching apparatuses 18-1 ~ 18-6 to be connected. Moreover, when the art of narrowing spaces between adjacent wavelengths is put into practical use, it would be sufficient to only increase a precision of separating wavelengths at each trunk station and branch station, while the optical branching apparatuses are left as they are, so that there will be an advantage of easily dealing with a high density wavelength-division multiplexing system. This is very useful for submarine optical cable systems, since most of the optical branching apparatuses are laid deep in the sea floor.

With the optical branching apparatus shown in FIG. 3, each add/dropping element 32b, 34b, and 36a is effectively usable by the arrangement of add/dropping the different wavebands on the pairs #1 and #2 of optical fiber lines. In this connection, referring to FIG. 2, for example, the optical branching apparatuses 182 and 18-3; and optical branching apparatuses 18-5 and 18-6 may respectively be made into one integral body.

With the optical branching apparatus shown in FIG. 3, add/dropping elements of same waveband are connected to up and down lines of the pair of optical fiber lines. However, it is apparent that add/drop elements of different wavebands may be selected for up and down lines of the same pair of optical fiber lines.

The TABLE of FIG. 1 is an example of division of wavebands. For wavelength-division multiplexing transmission system using the same number of eight wavelengths, the following division of wavebands may be selected.

FIG. 8 shows another example of division of wavebands. In FIG. 8, the eight wavelengths λ1~λ8 are divided into two wavebands of high and low, namely, wavebands H and L, of which the wavelengths λ1, λ3, λ5 and λ7 are allotted to the pair #1 of optical fiber lines, and the remaining wavelengths λ2, λ4, λ6 and λ8 are allotted to the pair #2 of optical fiber lines. With this division of wavelengths, depending on which of the waveband L or H is subject to add/drop on the pairs #1 and #2 of optical fiber lines, each branch station connected to the optical branching apparatus of either waveband H or L can utilize wavelengths in the following combinations.

Connection of the pair #1 of optical fiber lines with the optical branching apparatus of the waveband L allows access with wavelengths λ1 and λ3; connection with the optical branching apparatus of the waveband H allows access with wavelengths λ5 and λ7; and connection with the optical branching apparatus of wavebands L and H allows access with wavelengths λ1, λ3, λ5 and λ7. Similarly, connection of the pair #2 of optical fiber lines with the optical branching apparatus of the waveband L allows access with wavelengths λ2 and λ4, connection with the optical branching apparatus of the waveband H allows access with wavelengths λ6 and λ8; and connection with the optical branching apparatus of wavebands L, H allows access with wavelengths λ2, λ4, λ6 and λ8. Of course, the add/drop waveband of the optical branching apparatus to be connected to the pair #1 of optical fiber lines and the add/drop waveband of the optical branching apparatus to be connected to the pair #2 of optical fiber lines can be set independently of each other. However, in the case where one each optical fiber line for each waveband (including through or waveband EX) as shown in the TABLE of FIG. 3 is provided, and the optical branching apparatus, which effects add/drop of a desired waveband or wavebands by combining these discrete optical fiber lines on the pairs #1 and #2 of optical fiber lines, is used, the same waveband cannot be utilized for both pairs #1 and #2 of optical fiber lines.

Now referring to FIG. 8, two wavelengths (for example, λ2 and λ4) can be used, by one branch station, and, therefore, even after the cabals have been laid, an increase of traffic can be immediately dealt with by simply making additional works in the respective branch stations.

In FIG. 8, particular prohibited wavelength or wave-

lengths (for example, wavelengths λ2, λ4, λ6 and λ8 prohibited to use for the pair #1 of optical fiber lines) can be utilized for communication between branch stations, if there are no problems in setting a gain of repeater and a transmission margin.

FIG. 9 and FIG. 10 respectively show examples of division of eight wavelengths, of which two wavelengths are for communication between the trunk stations, and the remaining six wavelengths are divided into two wavebands of L, H. Here, too, in order to avoid a confusion caused by making accessible to both pairs #1 and #2 of optical fiber lines with the same wavelength, the respective wavelengths λ1 ~ λ8 are allotted to be solely used for either the pair #1 or the pair #2 of optical fiber lines. Namely, the wavelengths λ1, λ3, λ5 and λ7 are allotted to the pair #1 of optical fiber lines, and the remaining wavelengths λ2, λ4, λ6 and λ8 are allotted to the pair #2 of optical fiber lines.

In FIG. 9, the wavelength λ1 is allotted for communication between the trunk stations on the pair #1 of optical fiber lines, and the wavelength λ8 is allotted for communication between the trunk stations on the pair #2 of optical fiber lines. The wavelengths λ2, λ3, and λ4 constitute the waveband L, and the wavelengths λ5, λ6 and λ7 constitute the waveband H. In FIG. 10, the wavelengths λ1 and λ5 are allotted for communication between the trunk stations on the pair #1 of optical fiber lines, the wavelengths λ2, λ3 and λ4 constitute the waveband L, and the wavelengths λ6, λ7 and λ8 constitute the waveband H. FIG. 10 is different from FIG. 9 in that, in FIG. 10, the pair #2 of optical fiber lines is not used for communication between the trunk stations.

With the division of wavebands of FIG. 9 and FIG. 10, a trouble occurred in any branch cables does not affect the communication between the trunk stations at all. Further, with respect to the traffic in the wavebands L and H, if a trouble has occurred in a certain branch cable, the resulted affect of such troubled branch cable can be lessened, and the trouble can be easily dealt with, because the same optical signal reaches an entry port of a branch station which makes branching of the same waveband as that of the troubled branch cable, and such not-troubled branch station is made to receive the signal in place of the branch station connected with the troubled branch cable, by making required works in the not-troubled branch station.

FIG. 11 shows an example of division of wavebands for an increased capacity for communication between the trunk stations. The example is similar to the above described examples in that the wavelengths λ1~λ8 are alternately allotted to access either the pair #1 or #2 of optical fiber lines in order to allow easy separation of wavelengths at the receiving station, and to avoid confusion caused by making accessible to the pairs #1 and #2 of optical fiber lines with the same wavelength. Namely, the wavelengths λ1, λ3, λ5 and λ7 are allotted to the pair #1 of optical fiber lines, and the remaining wavelengths λ2, λ4, λ6 and λ8 are allotted to the pair #2 of optical fiber lines. And, the wavelengths λ1 and λ5 are used for communication between the trunk stations on the pair #1 of optical fiber lines; and the wavelengths λ4 and λ8 are used for communication between the trunk stations on the pair #2 of optical fiber lines. The wavelengths λ2 and λ3 constitute the waveband L; and the wavelengths λ6 and λ7 constitute the waveband H.

The example of waveband division of FIG. 11 is suitable for the case where a larger capacity is required for communication between the trunk stations, and a trouble occurred in a branch cable does not make any affect to the communication between the trunk stations.

FIG. 12 shows an example of division of wavebands for allotting three adjacent wavelengths to the same pair #1 or #2 of optical fiber lines. Here, the wavelengths λ1, λ2, λ3 and λ5 are allotted to the pair #1 of optical fiber lines; and the remaining wavelengths λ4, λ6, λ7 and λ8 are allotted to the pair #2 of optical fiber lines. The wavelength λ1 is for communication between the trunk stations on the pair #1 of optical fiber lines, and the wavelength λ8 is used for communication between the trunk stations on the pair #2 of optical fiber lines. The wavelengths λ2, λ3 and λ4 constitute the waveband L; and the wavelengths λ5, λ6 and λ7 constitute the waveband H.

FIG. 13 and FIG. 14 respectively show examples of division of wavebands wherein the waveband L consists of three wavelengths, and the waveband H consists of two wavelengths. In FIG. 13, the wavelengths λ1 ~ λ8 are alternately allotted to either the pair #1 or #2 of optical fiber lines. The wavelengths λ1 and λ5 are used for communication between the trunk stations on the pair #1 of optical fiber lines; and the wavelength λ8 is used for communication between the trunk stations on the pair #2 of optical fiber lines. The wavelengths λ2, λ3 and λ4 constitute the waveband L; and the wavelengths λ6 and λ7 constitute the waveband H.

In FIG. 14, the wavelength λ4 is used for communication between the trunk stations on the pair #1 of optical fibers; and the wavelengths λ4 and λ7 are used for communication between the trunk stations on the pair #2 of optical fiber lines. The wavelengths λ1, λ2 and λ3 constitute the waveband L; and the wavelengths λ5 and λ6 constitute the waveband H. In this case, the wavelength λ4 may be used for communications between the trunk stations commonly on the pairs #1 and #2 of optical fiber lines, without causing any problems, since the pairs #1 and #2 of optical fiber lines do not spatially overlap one upon the other.

The above description has been made for the use of two pairs of optical fiber lines as an example. But, basically the present invention can be applied for one pair of optical fiber lines or more than three pairs of optical fiber lines. Also, the above description has been made for a wavelength-division multiplexing transmission system comprising eight wavelengths, but, needless to say, the number of wavelengths for use may be more or less than eight wavelengths.

Further, the above description has been made mainly for the arrangement having the trunk stations disposed at both ends of the trunk cables, but it is readily understood that the present invention can also be applied for an arrangement having annular trunk cables.

Those skilled in the art will be understood from the foregoing description that the present invention can provide an optical transmission system capable of flexibly dealing with fluctuation of traffic with easy maintenance. Also, the invention provides an optical transmission system which can withstand troubles occurred in any of branch cables.

Claims

1. An optical transmission system of wavelength-division multiplex transmission comprising a trunk cable having one or more pairs of optical fiber lines, and one or more branch stations each connected to the trunk cable through optical branching means and branch cable means, respectively, the optical transmission system is characterized in that;

   wavelengths to be wavelength-division multiplexed are divided into a plurality of wavebands, and said optical branching means comprise add/dropping means for effecting add/drop of one or more desired wavebands on said trunk cable.

2. An optical transmission system as recited in Claim 1, wherein said plurality of wavebands respectively contain therein one or more wavebands which cannot be subjected to add/drop by said optical branching means.

3. An optical transmission system as recited in Claim 1 or 2, wherein said optical branching means comprise first add/dropping means for effecting add/drop of one or more wavebands on a first pair of optical fiber lines of said trunk cable, and second add/dropping means for effecting add/drop of one or more wavebands, which are different from those of the first add/drop means, on a second pair of optical fiber lines of said trunk cable.

4. An optical transmission system as recited in claim 3, wherein each said wavelength to be wavelength-division multiplexed is exclusively allotted to said first pair of optical fiber lines and said second pair of optical fiber lines.

5. An optical transmission system as recited in claim 4, wherein each said wavelength to be wavelength-division multiplexed is alternately allotted to said first pair of optical fiber lines and said second pair of optical fiber lines.

6. An optical transmission system as recited in one of the Claims 1 to 5 further comprising a first and a second trunk stations to be connected to both ends of said trunk cable.

7. An optical transmission system as recited in one of the Claims 1 to 6, wherein said optical branching apparatus comprise

   a plurality of add/drop optical transmission means having add/dropping means for effecting add/drop of a waveband which is subjected to add/drop respectively, when wavelengths to be wavelength-division multiplexed are divided into a plurality of wavebands, and
   through optical transmission means.

8. An optical branching apparatus as recited in Claim 8, wherein said plurality of add/drop optical transmission means are, except at least one add/drop optical transmission means, provided with optical amplifier means.

9. An optical branching apparatus as recited in Claim 7, wherein at least one of said add/drop optical transmission means with said optical amplifier means includes bypass means for selectively bypassing said add/dropping means.

10. An optical branching apparatus as recited in one of the Claims 7 to 9, wherein said add/drop optical transmission means and said through optical transmission means are respectively provided for each unit comprising a pair of optical fiber lines which consists of up and down optical fiber lines.

FIG. 1

Wavelength	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8
pair #1 of fiber lines	○	×	○	×	○	×	○	×
pair #2 of fiber lines	×	○	×	○	×	○	×	○
waveband	EX	L		M		H		EX

○ : Available

× :Prohibited

FIG. 2

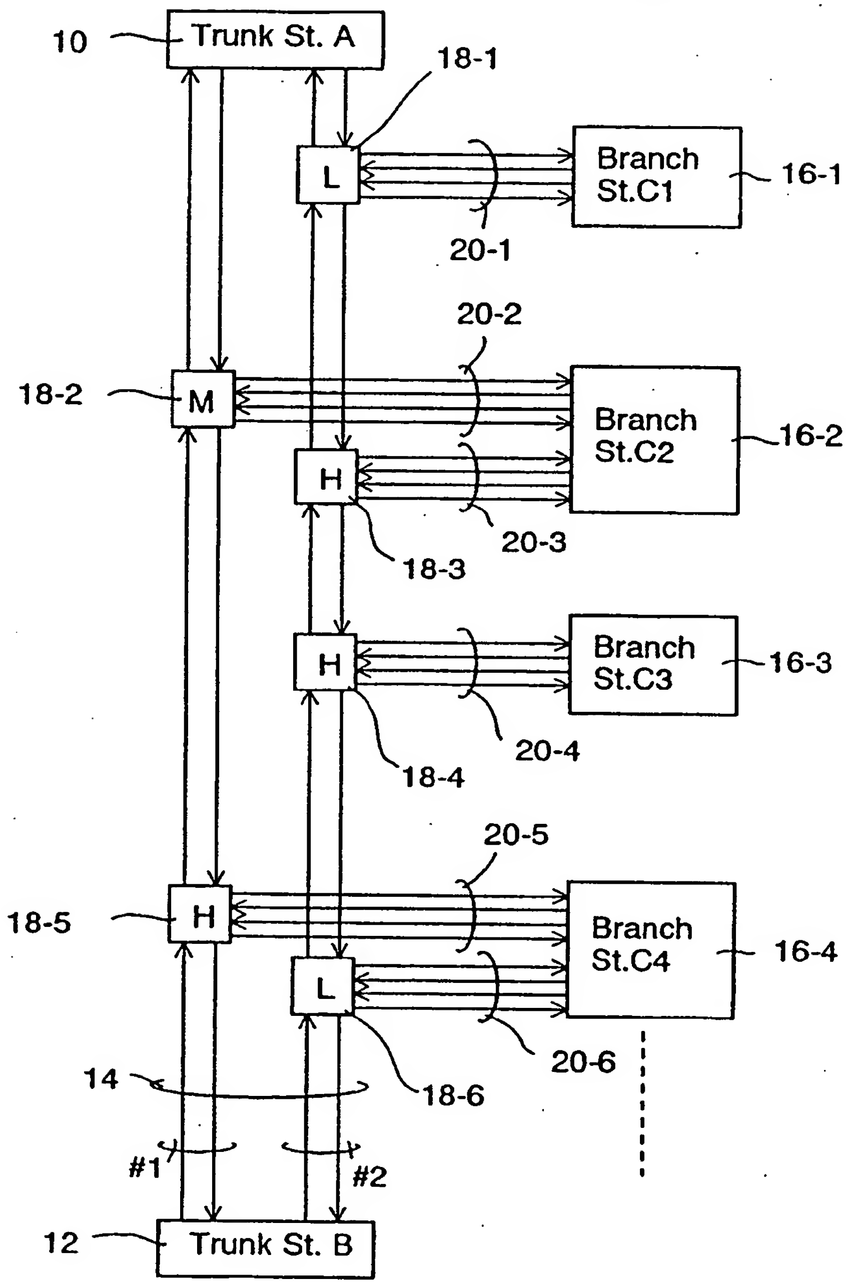
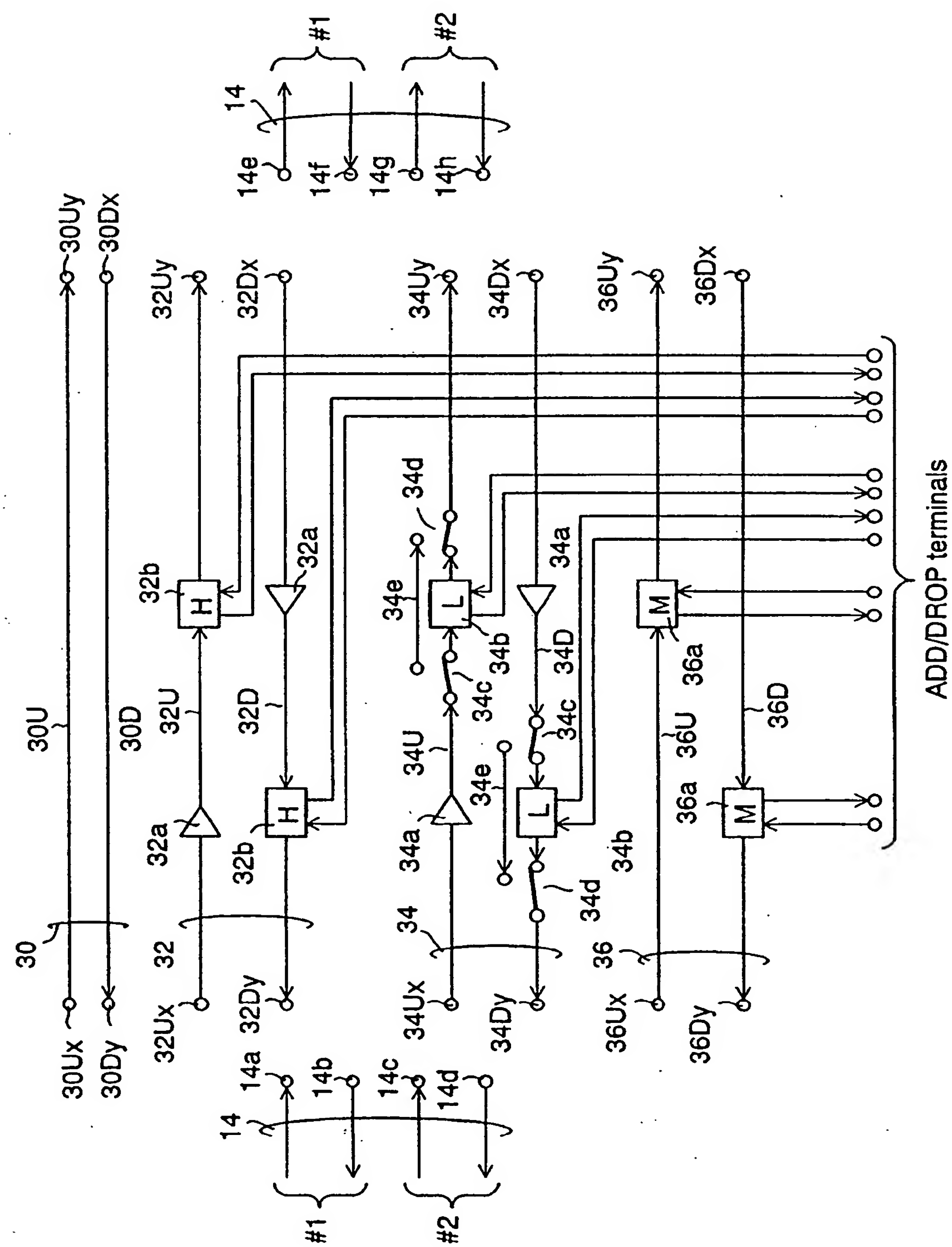

10
Trunk St. A
18-1
L
Branch St.C1
16-1
20-1
20-2
18-2
M
Branch St.C2
16-2
H
20-3
18-3
H
Branch St.C3
16-3
20-4
18-4
20-5
18-5
H
Branch St.C4
16-4
L
20-6
14
18-6
#1
#2
12
Trunk St. B

FIG. 3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30U
30D
30Ux
30Dy
30Uy
30Dx
32
32U
32D
32a
32b
32Ux
32Dy
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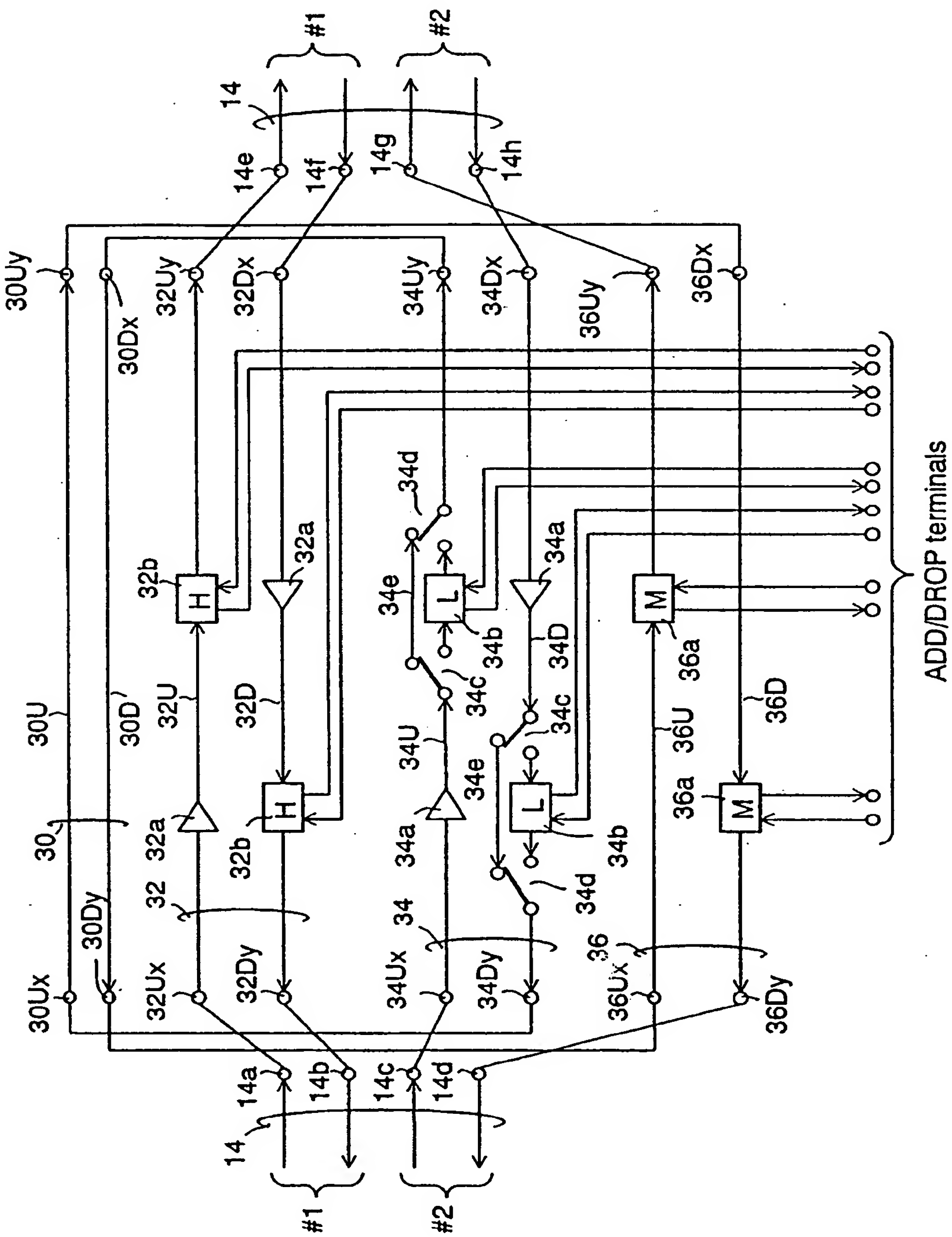
32Dx
H
34
34U
34D
34a
34b
34c
34d
34e
34Ux
34Dy
34Uy
34Dx
L
36
36U
36D
36a
36Ux
36Dy
36Uy
36Dx
M
14
14a
14b
14c
14d
14e
14f
14g
14h
#1
#2
ADD/DROP terminals

FIG. 4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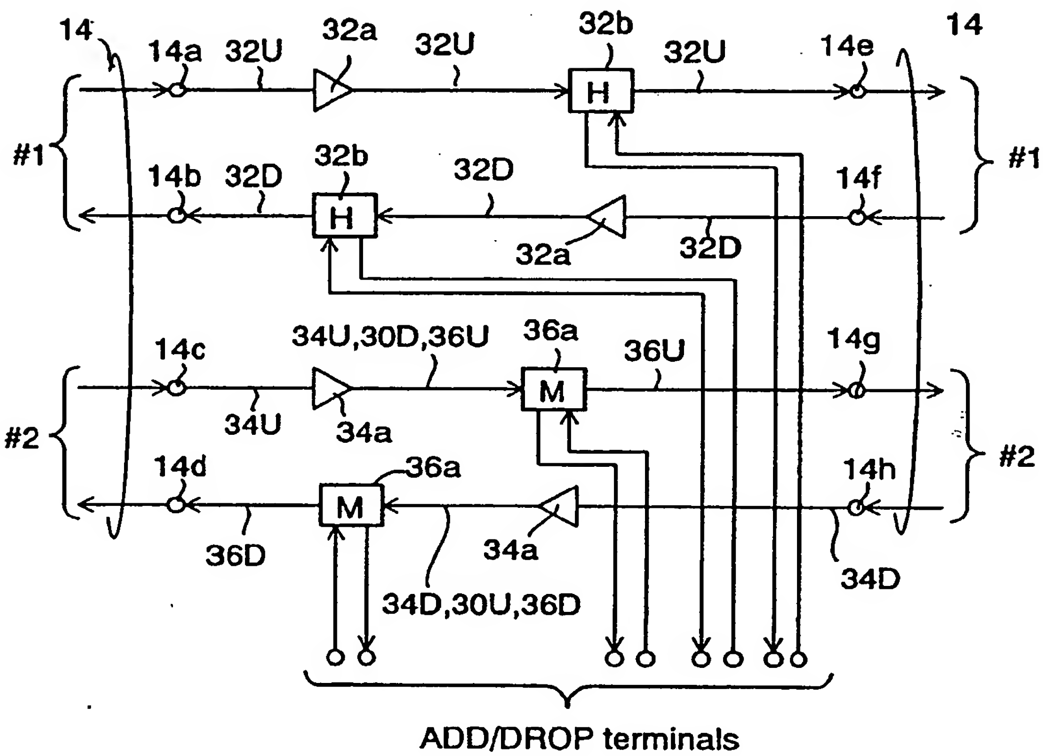
#2
14
14a
14b
14c
14d
14e
14f
14g
14h
30
30U
30D
30Ux
30Uy
30Dx
30Dy
32
32U
32D
32a
32b
32Ux
32Uy
32Dx
32Dy
H
34
34U
34D
34a
34b
34c
34d
34e
34Ux
34Uy
34Dx
34Dy
L
36
36U
36D
36a
36Ux
36Uy
36Dx
36Dy
M
ADD/DROP terminals

FIG. 5


14
14a
32U
32a
32U
32b
H
32U
14e
14
#1
14b
32D
32b
H
32D
14f
#1
32a
32D
14c
34U,30D,36U
36a
M
36U
14g
34U
34a
#2
14d
36a
M
14h
#2
36D
34a
34D,30U,36D
34D
ADD/DROP terminals

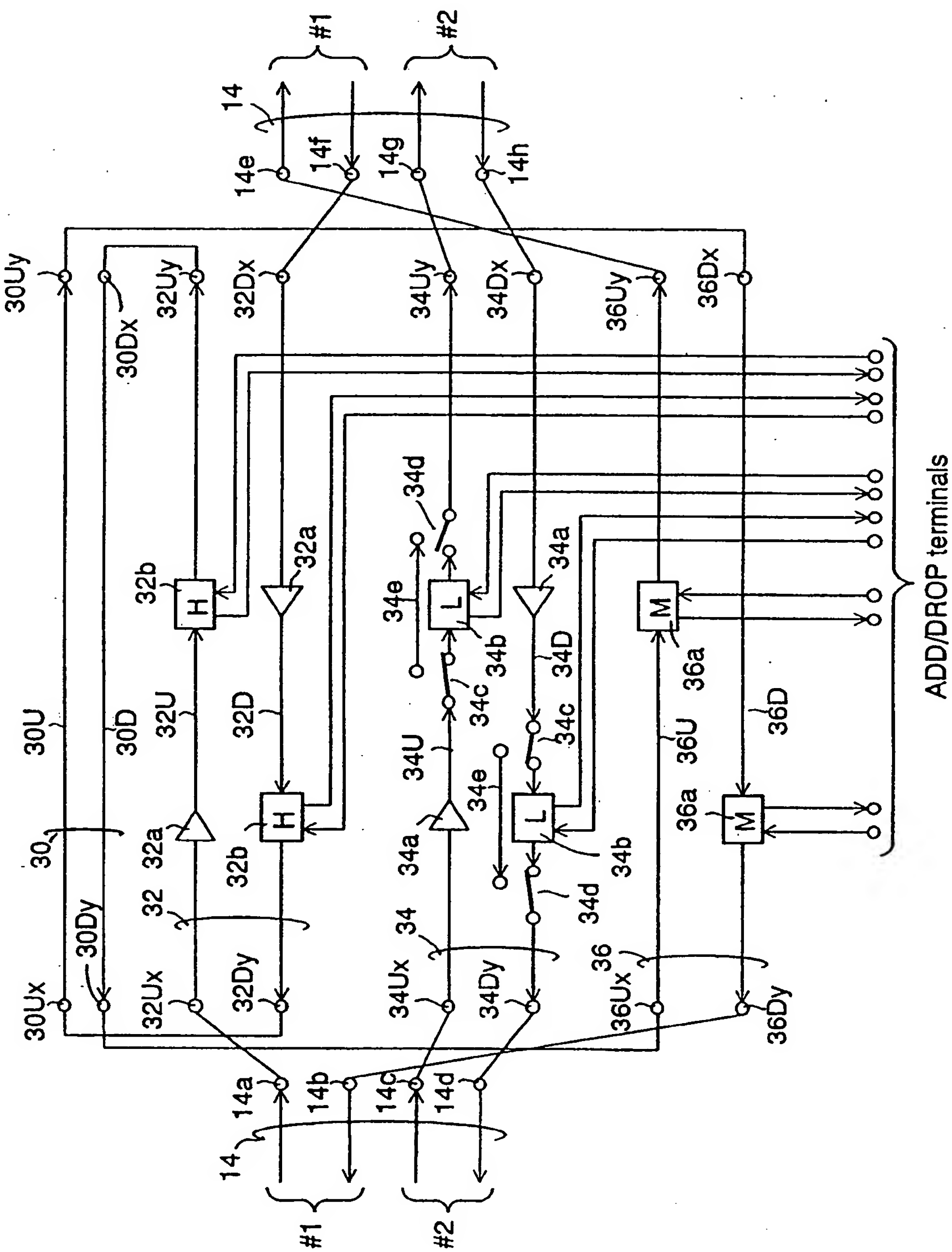
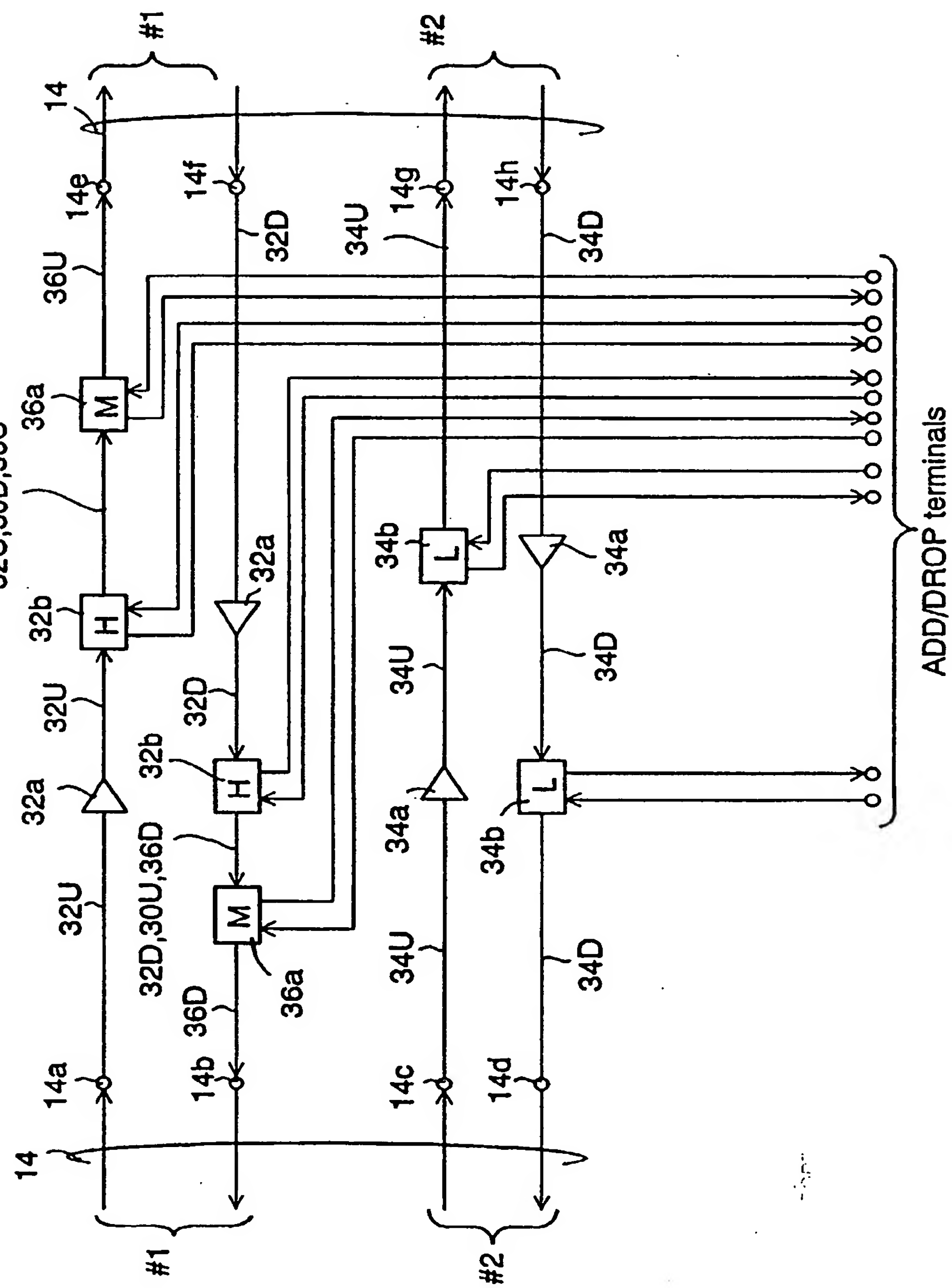

#1
#2
14
14a
14b
14c
14d
14e
14f
14g
14h
30
30U
30D
30Ux
30Uy
30Dx
30Dy
32
32U
32D
32Ux
32Uy
32Dx
32Dy
32a
32b
H
34
34U
34D
34Ux
34Uy
34Dx
34Dy
34a
34b
34c
34d
34e
L
36
36U
36D
36Ux
36Uy
36Dx
36Dy
36a
M
ADD/DROP terminals

FIG. 6

FIG. 7



14
#1
#2
14a
14b
14c
14d
14e
14f
14g
14h
32U
32a
32b
32D
32D,30U,36D
32U,30D,36U
36a
36U
36D
34U
34D
34a
34b
H
M
L
ADD/DROP terminals

FIG. 8

Wavelength	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8
pair #1 of fiber lines	○	✕	○	✕	○	✕	○	✕
pair #2 of fiber lines	✕	○	✕	○	✕	○	✕	○
waveband	L				H			

○ : Available

✕ :Prohibited

FIG. 9

Wavelength	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8
pair #1 of fiber lines	○	✕	○	✕	○	✕	○	✕
pair #2 of fiber lines	✕	○	✕	○	✕	○	✕	○
waveband	EX	L			H			EX

○ : Available

✕ :Prohibited

FIG. 10

Wavelength	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8
pair #1 of fiber lines	○	×	○	×	○	×	○	×
pair #2 of fiber lines	×	○	×	○	×	○	×	○
waveband	EX	L			EX	H		

○ : Available

× :Prohibited

FIG. 11

Wavelength	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8
pair #1 of fiber lines	○	×	○	×	○	×	○	×
pair #2 of fiber lines	×	○	×	○	×	○	×	○
waveband	EX	L		EX		H		EX

○ : Available

× :Prohibited

FIG. 12

Wavelength	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8
pair #1 of fiber lines	○	○	○	×	○	×	×	×
pair #2 of fiber lines	×	×	×	○	×	○	○	○
waveband	EX	L			H			EX

○ : Available

× :Prohibited

FIG 13

Wavelength	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8
pair #1 of fiber lines	○	×	○	×	○	×	○	×
pair #2 of fiber lines	×	○	×	○	×	○	×	○
waveband	EX	L			EX	H		EX

○ : Available

× :Prohibited

FIG. 14

Wavelength	λ1	λ2	λ3	λ4	λ5	λ6	λ7	λ8
pair #1 of fiber lines	○	○	×	○	○	×	×	×
pair #2 of fiber lines	×	×	○	○	×	○	○	×
waveband	L			EX	H			

○ : Available

× :Prohibited

FIG. 15

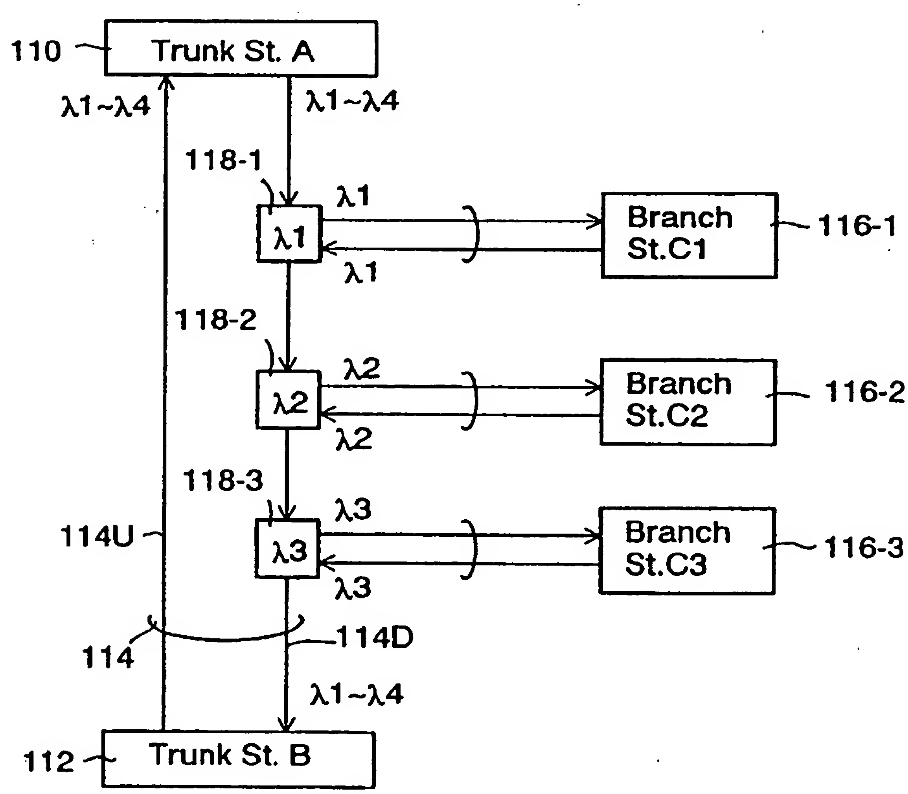
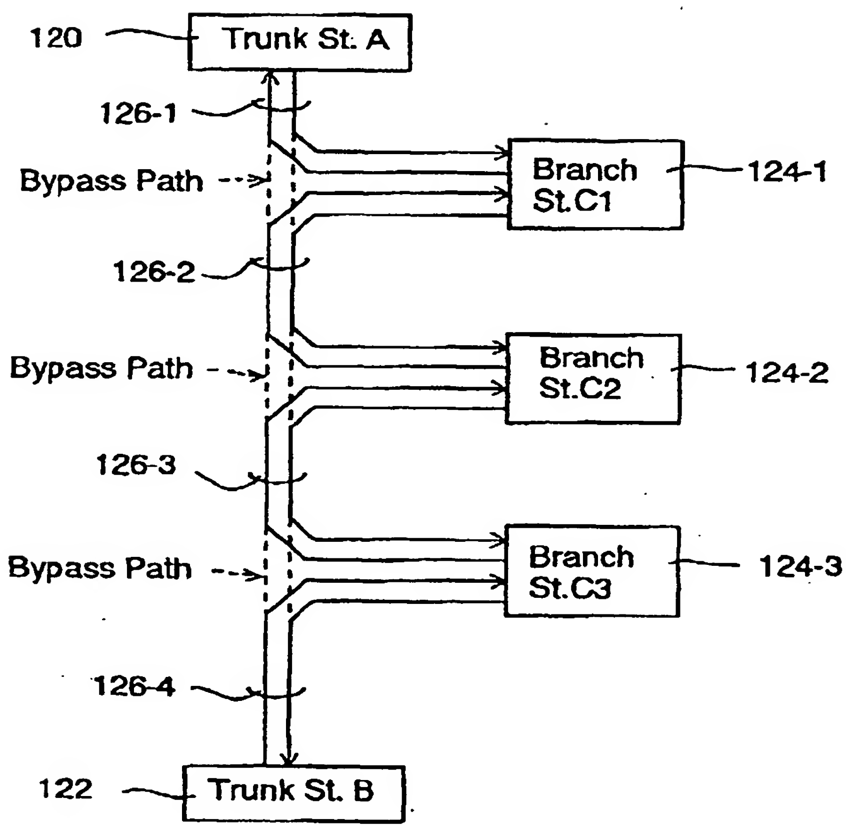


FIG. 16


120
Trunk St. A
126-1
Bypass Path
Branch
St.C1
124-1
126-2
Bypass Path
Branch
St.C2
124-2
126-3
Bypass Path
Branch
St.C3
124-3
126-4
122
Trunk St. B

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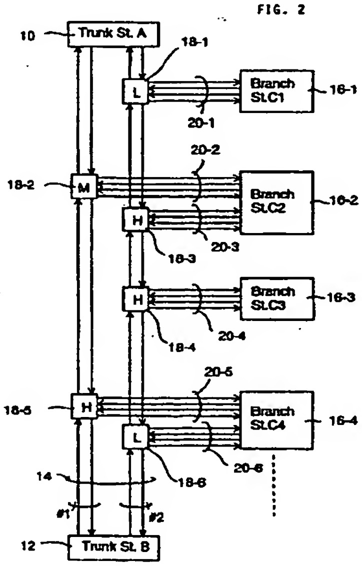
(54) Optical transmission system and optical branching apparatus

(57) In the optical transmission system of wavelength-division multiplexing, a plurality of wavelengths to be wavelength-division multiplexed are divided into a plurality of wavebands (for example, wavebands L, M and H, and the waveband EX for communication between trunk stations), each waveband consisting of one or more wavelengths. Each of branch stations 16-1 ~ 16-4 is connected with a trunk cable 14 through each of optical branching apparatuses 18-1 ~ 18-6 which is provided with one or more add/dropping elements to effect add/drop of the waveband(s) allotted to the associated one of the branch stations to be connected therewith. Optical branching apparatus for general purpose comprises an optical transmission path having add/dropping element for each of wavebands L, H and M, in addition to a through optical transmission path. A burden of having a great number of optical branching apparatuses in stock is reduced, since the optical paths to effect add/drop of wavebands allotted to branch stations 16-1~16-4 to be connected can be used selectively or in combination thereof.

FIG. 2



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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29 October 1998	Traverso, A

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& : member of the same patent family, corresponding document

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			TECHNICAL FIELDS SEARCHED (Int.Cl.6)

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